Chapter 4

Maintaining the Status Quo: The Business-as-Usual Scenario

The business-as-usual scenario (BAU), as described in Chapter 3, projects the future of the food and water sectors if current planning and trends in policies, management, and investments were to continue to 2025. BAU is used throughout the book as a benchmark against which the results of other scenarios are compared.[1]

THE WATER STORY

"Water demand," as discussed in Chapter 2, can be defined and measured in terms of withdrawals and actual consumptive uses (See Box 2.1). While water withdrawal is the most commonly estimated figure, consumptive use best captures actual water use, and most of our analysis utilizes this concept. Total global water withdrawal in 2025 is projected to increase 22 percent above 1995 levels under BAU to 4,772 cubic kilometers—consistent with other recent projections to 2025 including the Alcamo et al. (1998) medium scenario of 4,580 cubic kilometers, the Seckler et al. (1998) business-as-usual scenario of 4,569 cubic kilometers, and the Shiklomanov (1999) forecast of 4,966 cubic kilometers (excluding reservoir evaporation) (Table 4.1). The increase is much higher in developing countries, at 27 percent over the 30-year projection period.

The "criticality ratio," or the ratio of water withdrawal to total renewable water, is an indicator of water scarcity stress at the basin level (Alcamo, Henrichs, and Rösch 2000; Raskin 1997). The higher the criticality ratio, the more intensive the use of river basin water, and the lower the water quality for downstream users. Hence at high criticality ratios, water usage by downstream users can be impaired, and during low flow periods, the chance of absolute water shortages increases. There is no objective basis for selecting a threshold between low and high water stress, but the literature indicates that criticality ratios equal to or greater than 0.4

are considered "high water stress," and 0.8 "very high water stress" (Alcamo, Henrichs, and Rösch 2000).

Under BAU, the criticality ratio increases globally from 0.08 in 1995 to 0.10 in 2025 (Table 4.1) Although the criticality ratio is relatively low globally and for large aggregated regions because of the abundance of water in some of the component countries and basins that make up these aggregates, it is far higher for dry regions. In China, the criticality ratio increases from 0.26 in 1995 to 0.33 in 2025 (a 27 percent increase), and in India, the criticality ratio increases from 0.30 to 0.36 (a 20 percent increase). Water-scarce basins in northern China and northern and northwestern India have criticality ratios several times higher than these values (see also Boxes 4.1 and 4.2). In West Asia and North Africa (WANA), the ratio increases by 32 percent, from 0.69 to 0.90. While water stress is not particularly excessive at the global level under BAU, many regions and people face high and significantly worsening water stress over the projection period.

Table 4.1—Total water withdrawal by volume and as a percentage of renewable water

	Total water withdrawal (km^3)			Total withdrawal as a percentage of renewable water (%)		
	1995	BAU projections		1995	BAU projections	
Region/Country	baseline	2010	2025	baseline	2010	2025
Asia	2,165	2,414	2,649	17	19	20
China	679	759	846	26	29	33
India	674	750	815	30	33	36
Southeast Asia	203	240	287	4	4	5
South Asia excluding India	353	391	421	18	20	22
Latin America (LA)	298	354	410	2	2	3
Sub-Saharan Africa (SSA)	128	166	214	2	3	4
West Asia/North Africa (WANA)	236	266	297	69	81	90
Developed countries	1,144	1,223	1,265	9	9	10
Developing countries	2,762	3,134	3,507	8	9	10
World	**3,906**	**4,356**	**4,772**	**8**	**9**	**10**

Sources: 1995 baseline data for total withdrawals are author estimates based on Shiklomanov (1999) and Gleick (1993) for individual countries and regions; HPDGJ (1989), Qian (1991), NIHWR (1998), and CMWR (1990–98) for river basins in China; USGS (1998) for river basins in the United States; ESCAP (1995) and IMWR (1998–2000) for river basins in India. 1995 baseline data for renewable water are from Alcamo et al. (1998). 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates business-as-usual scenario; km^3, cubic kilometers.

Box 4.1—Water scarce basins

The analysis in this book primarily focuses on water and food futures at the global scale and for major countries and regions, but it is also essential to assess how changes in trends, policies, and investments will affect important water scarce river basins, where the impacts of changes may be particularly high. Therefore, selected results for individual river basins will be highlighted throughout the analysis, including the Yellow (Huanghe) and Haihe River basins in northern China, the parts of the Ganges and Indus River basins that lie within India. In addition, we highlight alternative futures for Egypt, which is virtually coterminous with the Nile River basin.

The Yellow River is the second largest river in China, traversing nine provinces on its 5,464 kilometer course through the northern heartland of China. The Yellow River basin is of utmost importance for China in terms of food production, natural resources, and socioeconomic development: it covers 7 percent of China's land area and supports 136 million people, or 11 percent of China's population. The total physical crop area in the basin is 12.9 million hectares, of which 31 percent is irrigated, but while it contains 13 percent of the total cultivated area in China, it holds only 3 percent of the country's water resources (CMWR 2002). Increased water scarcity in this basin is shown by interruption of flow in the lower Yellow River, declining groundwater levels, disappearing lakes, and silting up of river beds (Dialogue on Water and Climate 2002).

The Haihe River basin covers eight provinces and cities, including China's capital city of Beijing and China's fourth largest city, Tianjin, and has a population of 90 million. The basin extends over 3.3 percent of China's total area, supports about 10 percent of China's population, and holds 15 percent of China's industrial production and 10 percent of the country's total agricultural output. Total physical crop area amounts to 10.8 million hectares, 7.1 million hectares of which are irrigated (CMWR 2002). However, the Haihe basin has had a water deficit for over 25 years, potentially leading to significant water quality and quantity problems in this basin (Working Group on Environment in U.S.-China Relations 1998).

The Indus basin begins in Tibet and flows through India and Pakistan. In India, about 60 million people reside in the basin area, which covers the northern and northwestern states. The drainage area of 321,289 square kilometers of the Indus River basin encompasses nearly 10 per-

(continued)

Box 4.1—Continued

cent of the total geographical area of India. Cropland in the basin is about 9.6 million hectares, 5 percent of the total cropland of the country, of which about 30 percent is irrigated (IMWR 2002). The fight for water has been ongoing in the Indus, with water tables dropping because of groundwater overpumping and basins running dry the for portions of the year (Postel 2002). Water scarcity is an international issue in the Indus; after the Independence of India and Pakistan, they nearly went to war over this basin, a water treaty was established in 1960 that has proven resilient (Postel and Wolf 2001).

The Ganges, the subcontinent's largest and most important river, rises in Nepal and flows 1,400 miles through three densely populated Indian states—Uttar Pradesh, Bihar, and West Bengal—before entering Bangladesh and flowing into the Bay of Bengal (Hinrichsen, Robey, and Upadhyay 1998). The Ganges River basin within India encompasses nearly 26 percent of the total geographical area of the country, and is inhabited by 323 million people. Physical cropland in the Indian part of the basin is estimated to be 58 million hectares or 30 percent of the total cropland of the country of which 20 percent is irrigated (IMWR 2002). Even though the Ganges does not seem water-scarce based on total annual flows, it often experiences severe water stress from January to April, and floods during other months (Biswas, Uitto, and Nakayama 1998).

The Nile River, the longest river in the world, flows from its major source Lake Victoria in east central Africa, north through Uganda and into Sudan where it meets the Blue Nile at Khartoum, which rises in the Ethiopian highlands. From the confluence of the White and Blue Nile, the river continues to flow northwards into Egypt and on to the Mediterranean Sea (Nile Basin Initiative 2002). Egypt gets 97 percent of its water from this river. However, as the countries in the upper Nile basin continue to use more water given rising population and increasing economic growth, Egypt's water share could decline (McNeeley 1999). In 1995, the cultivated area in Egypt was 3.3 million hectares, or 3.2 percent of the total area and almost all cropland is irrigated. As mentioned above, the Nile River is by far the dominant water source of water for Egypt and 90 percent of the cropland is in the Nile Valley and delta area (FAO 1995). Thus the results presented for Egypt are closely indicative of change in the Nile River basin within Egypt.

Non-Irrigation Water Demand-Consumptive Use

Non-irrigation consumptive use varies by sector and at the basin, country, and regional levels (Table 4.2). At a global level, all non-irrigation uses increase 225 cubic kilometers over the period, an increase of 62 percent by 2025. All non-irrigation uses are projected to increase significantly, with a large share of the increase occurring in developing countries.

Box 4.2—Water scarce basins under the business-as-usual scenario: Growing scarcity

Income and population growth drive rapid increases in water consumption in the domestic, industrial, and livestock sectors. Total non-irrigation water consumption increases by 75 percent in the Yellow River basin, 83 percent in the Haihe River basin, 88 percent in Egypt, and by over 100 percent in the Indus and the Ganges compared with 1995 levels. With limited water supply growth, this increase in non-irrigation demand is in large part at the expense of water supply for irrigation.

Water stress at the basin level, measured by the criticality ratio (ratio of withdrawals to total renewable water), also increases significantly from the already high levels in these basins under BAU. Even in 1995, the criticality ratios for these basin are high a) based on world and developing country averages, b) relative to the thresholds for all the selected basins compared with global and developing country averages, and c) relative to the indicative threshold levels of 0.40 for high water stress and 0.80 for very high water stress. And under BAU, these high stress levels intensify, with Egypt increasing from 0.99 to 1.08, the Yellow River basin from 0.89 to 1.11, the Haihe from 1.40 to 1.49, the Indus from 0.72 to 0.90, and the Ganges from 0.50 to 0.57. The level of water stress increases greatly across all basins in 2025, however. This critical level of water stress signals increasingly serious water scarcity problems in the future with probable poor water quality from high water reuse rates.

Although irrigated area increases by 23 percent in the Yellow River basin, 15 percent in the Haihe, 15 percent in Egypt, 28 percent in the Indus, and 29 percent in the Ganges, irrigation water consumption declines or barely increases. Compared with 1995, irrigation water consumption in 2025 declines by 19 percent in the Haihe and 6 percent in the Ganges; and increases by 7 percent in Egypt, 5 percent in the Yellow, and 12 percent in the Indus. Irrigation water supply reliability (IWSR) declines between 1995 and 2025 in each of the basins and

(continued)

Box 4.2—Continued

Egypt, with particularly large drops in the Haihe (22 percent) and the Ganges (19 percent).

Under BAU, crop yields increase through agricultural research and growth of fertilizer use and other inputs, raising total cereal production in each of the water scarce basins between 1995 and 2025. Cereal production is projected to increase by 48 percent in the Haihe, 45 percent in the Yellow, 54 percent in the Indus, and 50 percent in the Ganges River basins. But increasing water scarcity slows cereal production growth significantly. With the decline in IWSR, relative irrigated yields (compared to full water adequacy) decline dramatically. The relative irrigated cereal yield declines between 1995 and 2025 from 0.91 to 0.71 in the Yellow River basin, from 0.80 to 0.70 in the Haihe, from 0.88 to 0.71 in the Indus, from 0.83 to 0.67 in the Ganges, and from 0.66 to 0.59 in Egypt. Irrigated cereal yields in these basins thus range from 11 percent lower (Egypt) to 22 percent lower (Yellow) in 2025 than they would have been if irrigation water scarcity had been maintained at 1995 levels.

Domestic water demand makes up 8 percent of total potential demand in 1995, and is projected to increase to 11.5 percent by 2025 under BAU. Domestic demand rises rapidly with a projected global increase of 71 percent, and a doubling of demand in developing countries. Faster growth in developing countries results from their higher population growth and a relatively rapid increase of per capita water use from the existing low levels caused by income growth (Table 4.3). About 97 percent of population growth occurs in developing countries, and per capita domestic water use in developing countries is projected to increase by 8.3 cubic meters per year. In contrast, population in developed countries increases only 4.6 percent between 1995 and 2025, and per capita domestic water use increases by 6.4 cubic meters per year over the initial 48 cubic meter level. Per capita domestic water use declines under BAU in developed countries with the highest per capita water demand—a result of conservation and technological improvements. Hence, total domestic water demand in developed countries grows much more slowly than in developing countries at just 10 cubic kilometers by 2025.

Domestic water demand is differentiated as connected and unconnected households in both rural and urban areas.[2] We assessed the percentage of population connected and unconnected in rural and urban areas for various countries from 1995

Table 4.2—Non-irrigation consumptive water use, 1995, 2010, and 2025

Region/Country	Domestic (km^3)			Industrial (km^3)			Livestock (km^3)			Total Non-Irrigation (km^3)		
	1995 baseline estimates	BAU projections 2010	BAU projections 2025	1995 baseline estimates	BAU projections 2010	BAU projections 2025	1995 baseline estimates	BAU projections 2010	BAU projections 2025	1995 baseline estimates	BAU projections 2010	BAU projections 2025
Asia	79.1	121.8	156.7	48.3	75.3	90.7	11.7	17.9	25.6	139.1	215.0	273
China	30.0	48.0	59.4	13.1	24.5	31.1	3.4	5.3	7.4	46.5	77.8	97.9
India	21.0	32.1	40.9	7.2	13.8	15.7	3.3	5.3	8.1	31.5	51.2	64.6
Southeast Asia	13.9	21.4	30.4	11.2	15.3	20.9	1.7	2.8	4.1	26.8	39.5	55.4
South Asia excluding India	7.0	11.5	16.2	1.9	3.2	4.7	1.7	2.7	3.9	10.6	17.4	24.7
Latin America (LA)	18.2	25.0	30.7	17.9	25.3	29.9	6.9	9.5	12.5	43.1	59.8	73
Sub-Saharan Africa (SSA)	9.5	16.0	23.9	0.9	1.6	2.4	1.6	2.6	4.1	12	20.2	30.4
West Asia/North Africa (WANA)	7.1	10.2	13.1	4.6	6.9	8.7	1.8	2.5	3.3	13.4	19.6	25.1
Developed countries	58.7	64.5	68.6	94.7	112.8	113.8	15.3	16.9	18.2	168.6	194.2	200.6
Developing countries	110.6	169.5	221.0	62.2	98.3	121.4	21.8	32.1	45.2	194.5	299.9	387.5
World	**169.2**	**234.0**	**289.6**	**156.9**	**211.0**	**235.2**	**37.0**	**49.0**	**63.4**	**363.1**	**494.0**	**588.2**

Sources: 1995 baseline data for water consumption by sector are author estimates based on Shiklomanov (1999) and Gleick (1993) for individual countries and regions; HPDGJ (1989), Qian (1991), NIHWR (1998), and CMWR (1990-98) for river basins in China; USGS (1998) for river basins in the United States; ESCAP (1995) and IMWR (1998-2000) for river basins in India. Livestock data are from FAO (1986), Mancl (1994), and Beckett and Oltjen (1993). 2010 and 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates busines-as-usual scenario; km^3, cubic kilometers.

Table 4.3—Per capita domestic water demand

	Per capita consumption (m^3/person/year)		
	Baseline estimates	BAU projection	
Region/Country	1995	2010	2025
Asia	24.8	32.9	36.9
China	24.5	35.8	41.2
India	22.6	28.1	30.7
Southeast Asia	29.9	37.2	45.6
South Asia excluding India	23.7	27.4	29.6
Latin America (LA)	24.8	32.5	36.9
Sub-Saharan Africa (SSA)	18.3	21.2	21.9
West Asia/North Africa (WANA)	21.2	23.0	23.4
Developed countries	47.8	51.8	54.4
Developing countries	25.6	31.4	33.9
World	**30.3**	**35.0**	**37.2**

Sources: 1995 baseline data for total domestic water consumption are author estimates based on Shiklomanov (1999) and Gleick (1993) for individual countries and regions; HPDGJ (1989), Qian (1991), NIHWR (1998), and CMWR (1990–98) for river basins in China; USGS (1998) for river basins in the United States; ESCAP (1995) and IMWR (1998–2000) for river basins in India. Connected population are estimates based on WHO and UNICEF (2000) and FAO (2000). 2010 and 2025 data are IMPACT-WATER projections, 2002.
Notes: BAU indicates business-as-usual scenario; m^3/person/year, cubic meters per person per year.

to 2025 using data on the percentage of population connected (WHO and UNICEF 2000) the projected total urban and rural population in each country (FAO 2000), and on our assessment of recent trends in development of urban water systems.

Table 4.4 shows the per capita water demand for connected and unconnected rural and urban areas in selected countries and regions. Per capita demand is higher in urban than in rural areas, and connected demand is higher than unconnected demand.[2] Worldwide, the 1995 per capita demand in unconnected rural households is 55 percent of the connected demand, increasing to 60 percent by 2025; the per capita demand in unconnected urban households is 57 percent of the connected demand and decreases to 52 percent by 2025 as a result of large increases in urban population—especially in developing countries.

The growth in global industrial water demand is also rapid, with demand increasing by 50 percent for the world as a whole. (Table 4.2). The majority of this increase also occurs in developing countries, where demand almost doubles. The 1995 estimate for industrial water consumption in the developed world is much greater than that of the developing world; however, by 2025 developing world industrial water demand is projected to increase to 121 cubic kilometers, 7 cubic kilometers greater than the level in the developed world. The intensity of industrial water use (water demand per $1,000 of GDP) decreases significantly worldwide, especially

Table 4.4—Per capita domestic water demand for connected/unconnected households in rural and urban areas under the business-as-usual scenario, 1995 and 2025

	Annual consumption (m^3/person/year)							
	1995 baseline estimates				2025 BAU projections			
	Rural		Urban		Rural		Urban	
Region/Country	Connected	Unconnected	Connected	Unconnected	Connected	Unconnected	Connected	Unconnected
Asia	27.1	17.6	41.8	25.5	29.7	18.9	52.4	27.8
China	25.7	17.1	44.3	26.9	27.6	18.4	64.4	28.7
India	26.8	17.9	38.7	23.4	27.8	18.4	43.0	24.1
Southeast Asia	29.6	19.2	43.3	26.1	38.2	23.6	56.8	32.0
South Asia excluding India	25.7	17.3	36.4	23.2	28.2	18.9	36.0	27.5
Latin America	27.2	17.6	41.7	25.5	29.7	18.9	52.4	27.8
Sub-Saharan Africa	18.8	12.8	29.2	17.8	19.5	13.1	29.1	18.0
West Asia/North Africa (WANA)	18.3	10.6	25.7	17.8	17.0	10.0	27.0	15.8
Developed countries	47.0	22.3	49.3	28.6	48.8	33.9	55.7	34.8
Developing countries	25.2	16.9	39.1	24.7	27.0	17.6	45.5	24.9
World	**31.0**	**17.0**	**43.4**	**24.8**	**29.3**	**17.7**	**48.1**	**25.1**

Sources: 1995 baseline data for total domestic water consumption are author estimates based on Shiklomanov (1999) and Gleick (1993) for individual countries and regions; HPDGJ (1989), Qian (1991), NIHWR (1998), and CMWR (1990–98) for river basins in China; USGS (1998) for river basins in the United States; ESCAP (1995) and IMWR (1998-2000) for river basins in India; and WHO and UNICEF(2000) for connected and unconnected households. 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates business-as-usual scenario; m^3/person/year, cubic meters per person per year.

in developing countries (where initial intensity levels are very high) because of improved water-saving technology and demand policy in this sector (Table 4.5). The increase of total industrial production, however, still leads to an increase in total industrial water demand. Globally, industrial water demand is 7.4 percent of total potential demand in 1995, and is projected to increase to 9.4 percent of the total in 2025.

Direct water consumption by livestock is very small, but given the rapid increase of livestock production, particularly in developing countries, livestock water demand is projected to increase 71 percent from 1995 to 2025 (Table 4.2). Livestock water demand is a very small fraction of total consumptive water use in 1995 at only 2 percent, and increases only slightly to 3 percent by 2025 under BAU. Regionally, however, livestock can have much larger impacts on water use, and is becoming an even greater consumer of water, particularly in the developing world. While livestock water demand increases only 19 percent in the developed world, it is projected to more than double in the developing world, from 22 cubic kilometers in 1995 to 45 cubic kilometers in 2025.

Irrigation Water Demand: Consumptive Use

The potential demand or consumptive use for irrigation water is defined as the irrigation water requirement to meet full evapotranspirative demand of all crops included in the model, over the full potential irrigated area. Potential demand is thus the

Table 4.5—Industrial water use intensity

	Industrial water use intensity (m^3/\$1,000 of GDP)		
		BAU projection	
Region/Country	1995 baseline estimates	2010	2025
Asia	16.2	13.9	6.7
China	16.0	12.1	6.2
India	19.6	16.3	7.9
Southeast Asia	20.4	13.4	8.9
South Asia excluding India	18.3	15.6	11.7
Latin America (LA)	10.6	8.7	5.9
Sub-Saharan Africa (SSA)	6.3	6.3	5.8
West Asia/North Africa (WANA)	8.4	7.2	5.1
Developed countries	4.3	3.5	2.5
Developing countries	13.2	10.5	6.4
World	**5.9**	**5.1**	**3.6**

Sources: 1995 baseline data for total industrial water consumption are author estimates based on Shiklomanov (1999) and Gleick (1993) for individual countries and regions; HPDGJ (1989), Qian (1991), NIHWR (1998), and CMWR (1990–98) for river basins in China; USGS (1998) for river basins in the United States; ESCAP (1995) and IMWR (1998–2000) for river basins in India. 2025 data are IMPACT-WATER projections, 2002. GDP for all years is from World Bank (1998).
Notes: BAU indicates business-as-usual scenario; m^3, cubic meters; GDP, gross domestic product.

Table 4.6—Potential and actual consumptive use of water for irrigation and irrigation water supply reliability, 1995, 2010, and 2025

	Potential irrigation consumption (km³)			Actual irrigation consumption (km³)			Irrigation water supply reliability index (IWSR)		
	1995 baseline	BAU projections		1995 baseline	BAU projections		1995 baseline	BAU projections	
Region/Country	**estimates**	**2010**	**2025**	**estimates**	**2010**	**2025**	**estimates**	**2010**	**2025**
Asia	1,130.1	1,197.9	1,230.2	920.2	910.4	933.3	0.81	0.76	0.76
China	279.4	285.4	291.2	244.2	225.5	230.9	0.87	0.79	0.79
India	399.6	440.5	465.9	321.3	321.6	331.7	0.80	0.73	0.71
Southeast Asia	98.2	102.1	106.3	85.5	87.8	91.9	0.87	0.86	0.86
South Asia excluding India	205.3	215.5	225.0	163.2	168.1	169.4	0.79	0.78	0.75
Latin America (LA)	106.8	121.1	128.8	88.3	89.6	96.9	0.83	0.74	0.75
Sub-Saharan Africa (SSA)	68.5	78.0	87.3	50.3	55.4	62.9	0.73	0.71	0.72
West Asia/North Africa (WANA)	156.1	170.7	184.2	121.6	128.0	137.1	0.78	0.75	0.74
Developed countries	312.8	314.2	308.2	271.7	267.1	276.9	0.87	0.85	0.90
Developing countries	1,444.8	1,557.7	1,615.6	1,163.8	1,168.3	1,215.5	0.81	0.75	0.75
World	**1,757.6**	**1,864.3**	**1,923.8**	**1,435.5**	**1,435.5**	**1,492.3**	**0.82**	**0.77**	**0.78**

Sources: 1995 baseline data for irrigation water consumption are author estimates based on Shiklomanov (1999) and Gleick (1993) for individual countries and regions; HPDGJ (1989), Qian (1991), NIHWR (1998), and CMWR (1990-98) for river basins in China; USGS (1998) for river basins in the United States; ESCAP (1995) and IMWR (1998-2000) for river basins in India. 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates business-as-usual scenario; km³, cubic kilometers.

demand for irrigation water in the absence of any water supply constraints. Actual irrigation consumptive use is the realized water demand, given the limitations of water supply for irrigation. The proportion of potential demand realized in actual consumptive use is the irrigation water supply reliability index (IWSR), which is defined as the ratio of water supply available for irrigation over potential demand for irrigation water. The average potential and actual irrigation water demands and the IWSR resulting from the 30 climate scenarios are shown in Table 4.6. Compared with other sectors, the growth of irrigation water potential demand is much lower, with 12 percent growth in potential demand during 1995–2025 in developing countries, and a slight decline in potential demand in developed countries.

Under BAU, Sub-Saharan Africa (SSA) is projected to have the highest percentage increase in potential irrigation water demand, at 27 percent, while Latin America (LA) experiences the second highest growth, at 21 percent. Each of these regions has a high percentage increase in irrigated area from a relatively small 1995 level. India is projected to have by far the highest absolute growth in potential irrigation water demand—66 cubic kilometers (17 percent)—given relatively rapid growth in irrigated area from an already high 1995 level. WANA increases by 18 percent (28 cubic kilometers, mainly in Turkey), and China experiences a much smaller increase of 4 percent (12 cubic kilometers).

Water for Irrigation: Increasing Scarcity

Actual consumptive use of irrigation water worldwide is projected to grow more slowly than potential consumptive use, with an increase of only 4 percent (Table 4.6). In developing countries, consumptive use for irrigation increases from 1,164 cubic kilometers in 1995 to 1,216 cubic kilometers in 2025, an increase of 4 percent. This is of critical importance because irrigation water demand in developing countries is projected to be increasingly supply-constrained, with a declining fraction of potential demand being met over time.

For developing countries, the IWSR declines from 0.81 in 1995 to 0.75 in 2025 (Table 4.6). Relatively dry basins that face rapid growth in domestic and industrial demand, or experience slow improvement in river basin efficiency, or have rapid expansion in potential irrigated area without adequate increase in storage or withdrawal capacity, show even greater declines in water supply reliability. For example, in China's Yellow River basin, which mainly grows wheat and maize, the IWSR is projected to decline from 0.80 to 0.75, and in the Ganges of India the IWSR declines from 0.83 to 0.67. More severe increases in water scarcity occur in both China and India than in the developing countries as a whole.

In the developed world, water-scarce basins such as the Colorado and White-Red basins in the United States also face increasing water scarcity in the future. Developed countries as a whole, however, show a sharp contrast to the developing world in that their irrigation water supply is projected to grow faster than potential demand, partially compensating at the global level for shortfalls in the developing world. Over the full projection period, irrigation water supply in the developed world increases by 5.2 cubic kilometers, while the corresponding demand decreases by 4.6 cubic kilometers. Irrigation demand in the developed world as a whole declines because basin efficiency increases sufficiently to more than offset the very small increase in irrigated area. As a result, after initially declining from 0.87 to 0.85 in 2010, the IWSR improves to 0.90 in 2025 as a result of slowing domestic and industrial demand growth in later years (and actual declines in total domestic and industrial water use in the United States and Europe) and improved efficiency in irrigation water use. The divergence between trends in developing and developed countries indicates that agricultural water shortages become worse in the former even as they improve in the latter, providing a major impetus for the expansion in virtual water transfers through agricultural trade.

By 2025 under BAU, basins and countries with IWSR values less than 0.75 (a 25 percent water shortage relative to potential irrigation demand) include the Huaihe River basin, Haihe River basin, the Yellow River basin, most basins in India (including the Ganges River basin), as well as basins in central Asia, and most countries in LA, SSA, and WANA. IWSR remains above 85 percent in most developed countries and basins because of slow growth or declining water demand for domestic and industrial uses; however, even when the IWSR remains relatively high over time, irrigation is susceptible to considerable downside risk. Some basins in the United States, including the Colorado, Rio Grande, downstream Mississippi, Missouri, Texas Gulf, and White-Red-Arkansas River basins have an IWSR as low as 0.60 in some dry years in the latter stages of the projection period, which means as much as 40 percent of irrigation water demand cannot be satisfied in those years.

River basins in northern China display different water supply trends than those in the south. The ratio of irrigation water supply to demand in northern China is projected to remain below 0.8 in most years, and falls as low as 0.50 in some dry years. Southern China has IWSR values above 0.85 in most years, although this ratio falls as low as 0.50 in some particularly dry years.

The IWSR falls as low as 0.30 to 0.40 in some basins in western and northwestern India, particularly after 2015. Dramatic drops to approximately 30 percent may occur in some dry years or years with uneven intrayear rainfall distribution in other Indian basins. For the major cereal production basin, the Ganges, the IWSR is projected to decline from 0.83 in 1995 to below 0.67 percent by 2025.

LA countries maintain their base year water supply reliability under BAU, which measures below 0.75 in Mexico, Brazil, Argentina, and Colombia, and 0.79 percent in other LA countries—with Mexico undergoing slight declines. SSA countries, however, are projected to have widely varying agricultural water supply conditions. Nigeria has a low reliability of 0.57 along with considerable downside variance, and northern SSA undergoes a slight decline from 0.74 in 1995 to 0.69 in 2025. Central and western SSA undergo a larger decline from 0.90 to 0.80, while southern and eastern SSA maintain an average annual reliability of 0.77 with a relatively high variance. In WANA, the year-to-year variability is relatively small, but all countries experience declining reliability over the projection period with a decrease of 3 percent in Egypt, 4 percent in Turkey, and 5 percent in other countries in WANA.

Among South Asian countries, Bangladesh experiences the highest variance in water supply reliability with an average of around 75 percent between 1995 and 2010, declining to 70 percent between 2010 and 2025. Pakistan and other South Asian countries (excluding India) have relatively low variances, but average reliability is projected to decline from 80 to 70 percent in Pakistan and from 88 to 83 percent in other countries.

All Southeast Asian countries have high water supply reliability with averages between 0.67 and 0.88, depending on the country and time period. Water supply variances are also high and widen in the latter years of the projection period. In east Asia, excluding China, South Korea is projected to have a high variance in annual water supply reliability and a high average of 0.78 to 0.96.

Causes of Water Supply Constraints

Water shortages are caused by different factors in different countries. In the modeling framework, the causes of water shortages can be classified as source limits and infrastructure constraints. Source limits for irrigation water supply may come from fluctuation of natural sources (precipitation and runoff), and from increased non-irrigation water demands including domestic, industrial, and environmental water demand. Infrastructure constraints can be caused by insufficient reservoir storage or withdrawal facilities. The relative importance of these factors in a specific basin can help prioritize the need for different water development policies including infrastructure investment and policy reform that enhance basin efficiency. In the model, the relative importance of these factors can be identified through the constraint equations related to each of the factors such as infrastructure capacity, environmental requirements, and source balance. After the model is solved, the status of all the constraints and the IWSR can be examined. If the IWSR is below 0.95 and one of the corresponding constraints is contingent (reaching the lower or upper bound), then we conclude that the water shortage is caused by the factor(s) with the contingent constraint(s). For example, if the IWSR is 0.85, and the water supply reaches the source limit, then the water shortage is caused by the source limit.

In the United States, source limits occur in the Rio Grande and Colorado River basins in some dry years. Late in the projection period, the Missouri, Texas Gulf, and White-Red-Arkansas River basins may suffer water shortages of up to 40 percent in some dry years to maintain non-irrigation demands and environmental water requirements. Australia also has source shortages in some dry years. In China, serious source shortages are possible in the Haihe River basin, inland basins of northwest China, the Yellow River basin, and the Huaihe River basin. The Huaihe River basin and the Yellow River basin also have infrastructure constraints in some dry years (when water requirement from irrigation is large to make up for lack of rainfall) because the limits of withdrawal capacity are reached. Although it is seemingly paradoxical that withdrawal capacity could be a constraint when water supply is low, low rainfall also increases the proportion of crop water demand that must be met from irrigation. Basins in south and southeast China experience a dramatic drop (as much as 50 percent) in water supply in some years because of lack of storage capacity to deliver water during the dry season.

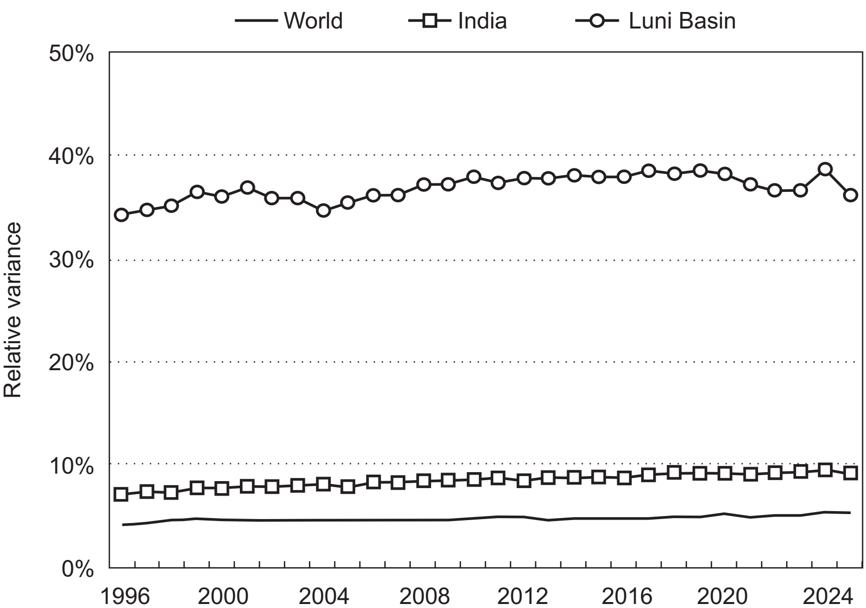
Infrastructure constraints cause water shortages of as much as 60–70 percent in some basins in western and northwestern India after 2015, especially because of insufficient reservoir storage. The same problem could occur in some basins in southern and eastern India where internal rainfall distribution is uneven. The Ganges River basin is also constrained by storage and water withdrawal capacity in later years, particularly after 2015.

Many LA countries face water withdrawal capacity constraints, with Mexico and Argentina requiring more storage for intra and interyear regulation in later years. The countries in WANA require more storage (with the exception of Egypt), and Turkey is also constrained by the water withdrawal capacity limit. Egypt has substantial source problems under BAU, particularly after 2010. All regions of SSA and most Asian countries need more storage or larger withdrawal capacity to meet growing demands for water. For other developed countries and regions (including western and eastern Europe, Russia, Australia, Oceania, and Japan) agricultural water shortages occur in some dry years, mainly as a result of the need to meet environmental and other non-irrigation demands and water withdrawal capacity limitations.

Variability in Irrigation Water Demand and Supply

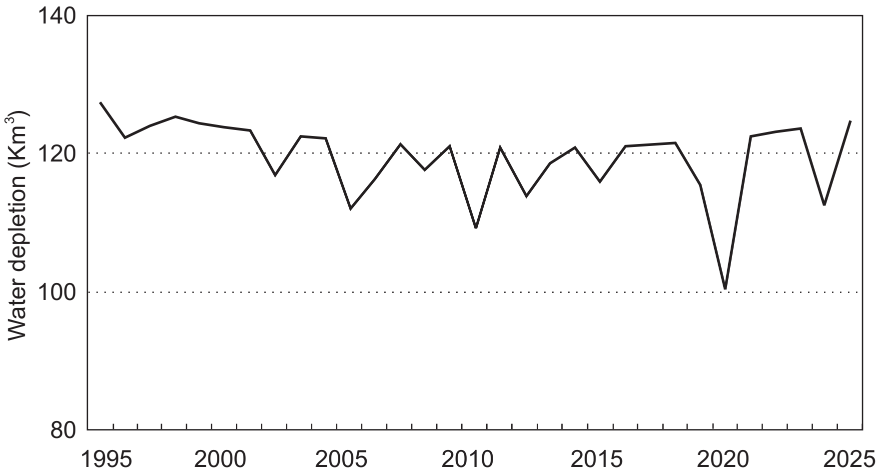
Climate variability leads to variability and risk to irrigation water supply availability under existing and projected water supply infrastructure. Low rainfall years can lead to severe water shortages even in regions in which water is relatively plentiful in most years. Water supply variability in a specific year can be assessed based on the multiple climate simulations or through changes in year-to-year variation in supply for a single climate run. Variability in irrigation water supply tends to be higher at smaller spatial scales because as the size of the spatial unit increases, local variability within the component units of the larger spatial unit is often counterbalanced by negative covariation between the component spatial units. This tendency is shown in Figure 4.1, which shows the standard deviation in irrigation water supplies from the 30 different climate scenarios at three spatial scales, the Luni River basin in India, India, and the world. The variability, as shown by the standard deviation in irrigation water supply, decreases as spatial scale increases. However, it is important to note that variability in irrigation water supply increases over time at all spatial scales. From 1995 to 2025, the standard deviation (variance divided by mean) of irrigation water supply increases from 4.1 percent to 5.0 percent in the world, 7.2 percent to 9.4 percent in India, and 34.2 percent to 37.2 percent in the Indian Luni River basin. Figure 4.2 shows the increase in variability even more dramatically for the year-to-year irrigation water supply in the Indian Ganges River basin under the climate regime of 1961–90. Irrigation water supply variability in the Ganges—and more generally in many relatively dry basins—becomes larger in later years because of the increase in non–irrigation water demand combined with water supply constraints—further illustrated below.

Figure 4.1—Coefficient of variation of irrigation water supply for the world, India, and the Indian Luni River Basin



Source: IMPACT-WATER assessments and projections, 2002.
Note: Coefficient of variation is the ratio of standard deviation over the average irrigation water supply.

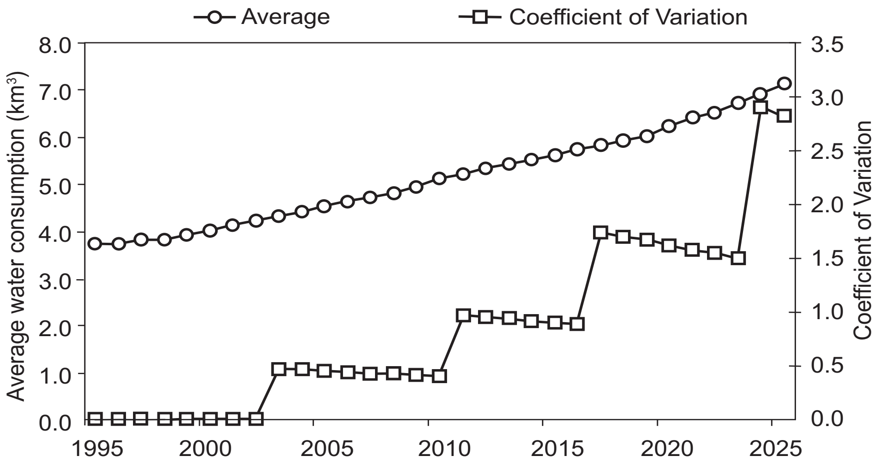
Figure 4.2—Irrigation water depletion in the Indian Ganges River Basin under the climate regime of 1961–90



Source: IMPACT-WATER assessments and projections, 2002.

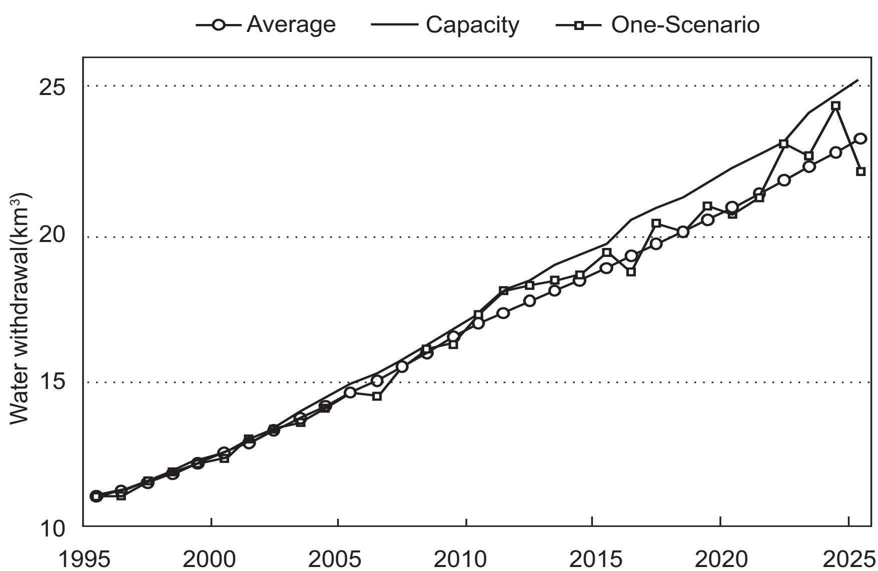
The degree and impact of irrigation water supply variability depends on climate variability, the degree of water scarcity, and the adequacy of water supply infrastructure. It is a fundamental problem that, in general, irrigation water supply variability increases precisely in those basins in which water scarcity is severe and increasing, such as river basins in the western United States, WANA, and northern China and India. Under these conditions, natural climate variability can cause severe shortages in irrigation water supply. On the other hand, in basins where water supply is relatively plentiful, the impact of climate variability may be low because inadequate water storage and withdrawal facilities are the dominant constraint on water supply even in dry years. In such basins or countries, annual climate variability barely affects agricultural water supply, although further development of water supply infrastructure raises water supply variability along with the average supply level from the climatic variability at higher levels of water supply. Nigeria typifies this situation, where the variability in irrigation water supply is very small until late in the projection period, when growth in both demand and supply bring source limitations into play. Figure 4.3 shows the average irrigation water consumption and the coefficient of variation in Nigeria. As can be seen, the variability increases with years. This can be explained by Figure 4.4, which presents water withdrawal capacity, computed average water withdrawal, and withdrawal under a single one climate scenario. In earlier years, actual water withdrawal reaches the capacity, and with little or no variability in water withdrawal. With the increase of water withdrawal capacity, variability with the actual water withdrawal increases, which leads to some significant variability in later years.

Figure 4.3—Coefficient of variation of irrigation water supply and the average supply in Nigeria during 1995–2025



Source: IMPACT-WATER assessments and projections, 2002.

Figure 4.4—Comparison of withdrawal capacity, average computed withdrawal, and withdrawal under one hydrologic scenario under the climate regime of 1961–90



Source: IMPACT-WATER assessments and projections, 2002.

WATER PRODUCTIVITY

One important strategy to increase food production in the face of increasing water scarcity is to increase the water productivity[3] (Molden 1997; Molden, Sakthivadivel, and Habib 2001; Barker and Kijne 2001). Water productivity (WP) is defined more specifically as crop yield (*P*) per cubic meter of water consumption including "green" water (effective rainfall) for rainfed areas and both green and "blue" water (diverted water from water systems) for irrigated areas (Equation 4.1). Water consumption (*WC*) includes beneficial (*BWC*) and nonbeneficial (*NBWC*) consumption (Equation 4.2). BWC directly contributes to crop growth at a river basin scale, and NBWC includes distribution and conveyance losses to evaporation and sinks, which are not economically reusable. BWC is characterized by water use efficiency in agriculture.

We use effective efficiency at the river basin scale, or basin efficiency (*BE*), (Keller, Keller, and Seckler 1996) to represent water use efficiency, which is a ratio of BWC to WC.

$$WP_{(kg/m^3)} = \frac{P_{(kg)}}{WC_{(m^3)}} \tag{4.1}$$

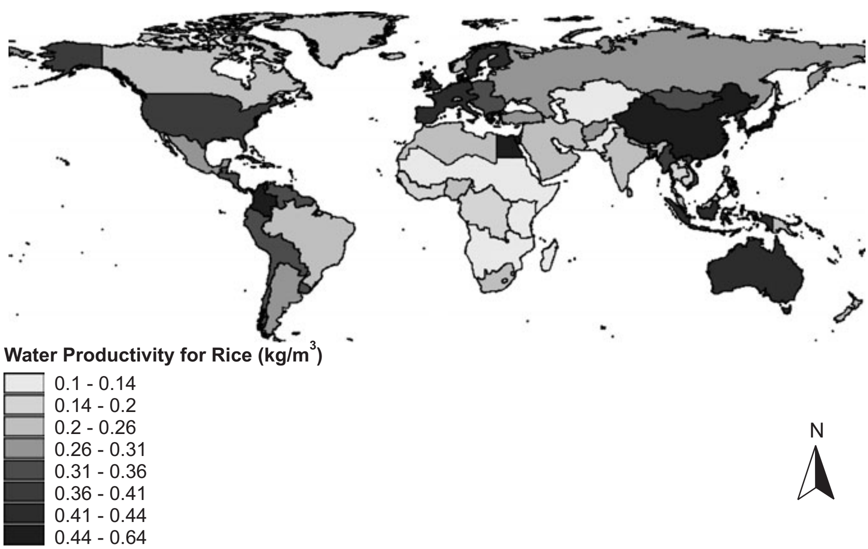
$$WC = BWC + NBWC = \frac{BWC}{BE} \tag{4.2}$$

Water productivity, defined above, varies from region to region and field to field, depending on many factors such as crop and climate patterns (if rainfall fits crop growth), irrigation technology and field water management, land and infrastructure, and input including labor, fertilizer, and machinery. Water productivity can be increased by either increasing crop yield (that is, increasing the numerator in Equation 4.1 through other inputs while maintaining constant water use level, or reducing water consumption and maintaining the yield level (that is, decreasing denominator), or both.

Water Productivity in 1995

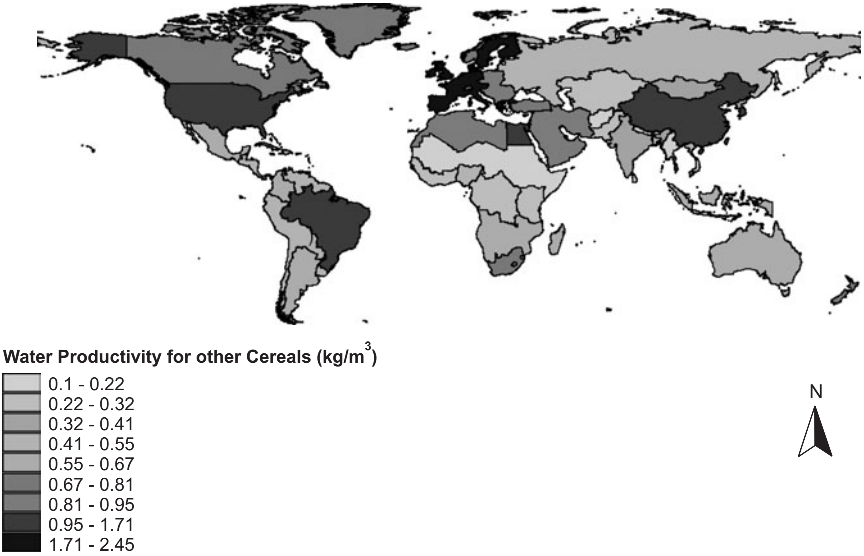
Figure 4.5 shows a global map of water productivity of irrigated rice, and Figure 4.6 shows a similar map of water productivity for irrigated cereals excluding rice. The basic elements of these maps are 36 countries and aggregated regions used in IMPACT (Rosegrant et al. 2001). Because rice usually consumes more water than other crops, the water productivity of rice is significantly lower than that of other cereals. The water productivity of rice ranges from 0.15 to 0.60 kilograms per cubic meter, while that of other cereals ranges from 0.20 to 2.40 kilograms per cubic meter. For both rice and other cereals, water productivity in SSA is the lowest in the world. The water productivity of rice is 0.10–0.25 kilograms per cubic meter in this region, with average yield of 1.4 metric tons per hectare and water consumption per hectare close to 9,500 cubic meters. For other cereals in SSA, the average yield is 2.40 metric tons per hectare, the water consumption per hectare is 7,700 cubic meters, and the average water productivity is 0.30 kilograms per cubic meter (ranging from 0.10 to 0.60 kilograms per cubic meter). Among developing countries, China and some Southeast Asian countries have higher water productivity for rice, ranging from 0.4 to 0.6 kilograms per cubic meter; however, the average for the developed world, 0.47 kilograms per cubic meter, is higher than the 0.39 kilograms per cubic meter for the developing world. For other cereals, water productivity is lower than 0.4 kilograms per cubic meter in South Asia, central Asia, northern and central SSA; ranges from 1.0–1.7 kilograms per cubic meter in China, the United States, and Brazil; and ranges from 1.7–2.4 kilograms per cubic meter in western European countries. The average water productivity of other cereals in the developed world is 1.0 kilograms per cubic meter, while in the developing world it is 0.56 kilograms per cubic meter.

Figure 4.5—Water productivity of rice, 1995



Source: IMPACT-WATER assessments, 2002.

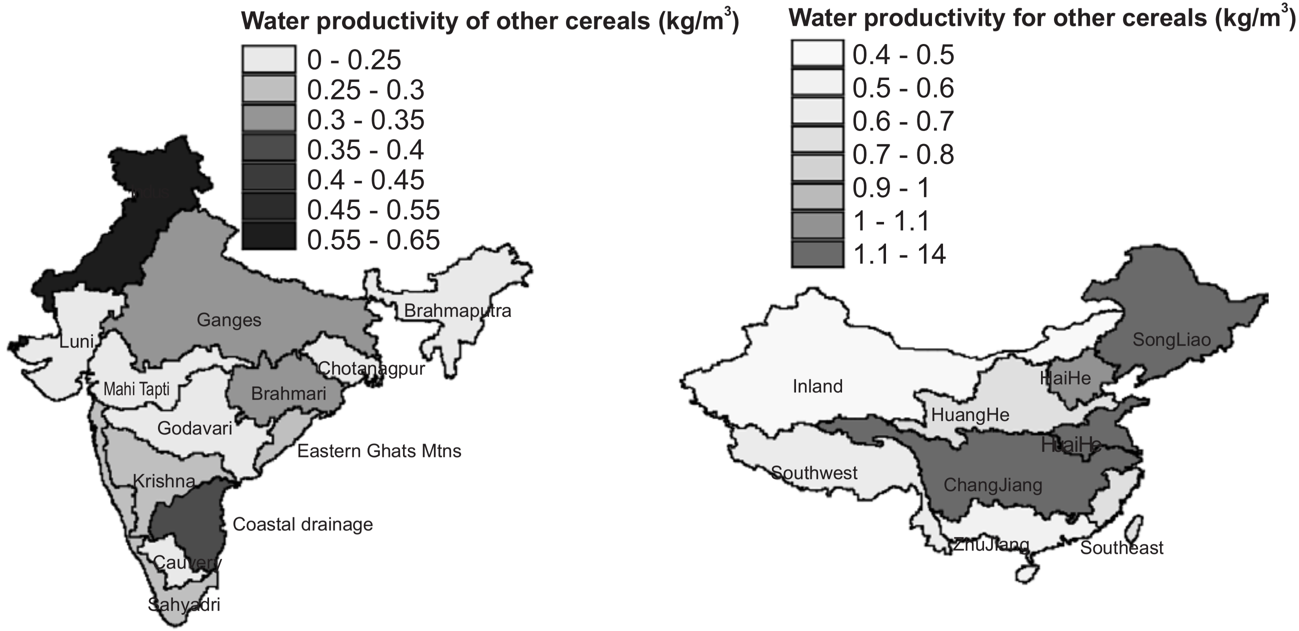
Figure 4.6—Water productivity of total cereals excluding rice, 1995



Source: IMPACT-WATER assessments, 2002.

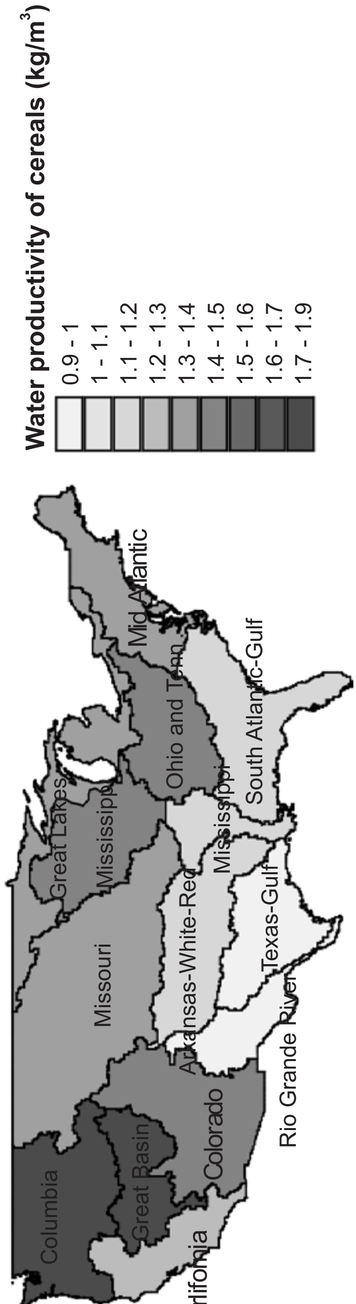
It should be noted that because of the level of aggregation, the numbers shown on these maps do not show the variation of water productivity within individual countries. Within some large countries, water productivity varies significantly. Figure 4.7 shows the water productivity of all cereals excluding rice in major river basins in China, India, and the United States. In China, water productivity for nonrice cereals ranges from 0.4 to 1.4 kilograms per cubic meter, with higher water productivity in the Yangtze River basin and northeast China (the Song-Liao River basin). Crop yields in these areas are relatively higher and water availability is relatively less restricted. However, in India, where nonrice cereal productivity ranges from 0.2 to 0.7 kilograms per cubic meter, higher water productivity occurs in the north (0.4–0.7 kilograms per cubic meter), where crop yield is higher but water availability is more restricted than in other areas. In the United States, water productivity ranges from 0.9–1.9 kilograms per cubic meter, with higher values in the north than in the south, and the highest in the northwestern regions.

Figure 4.7—Water productivity of total cereals in river basins in China, India, and the United States excluding rice, 1995



Source: IMPACT-WATER assessments, 2002.

Figure 4.7—Continued



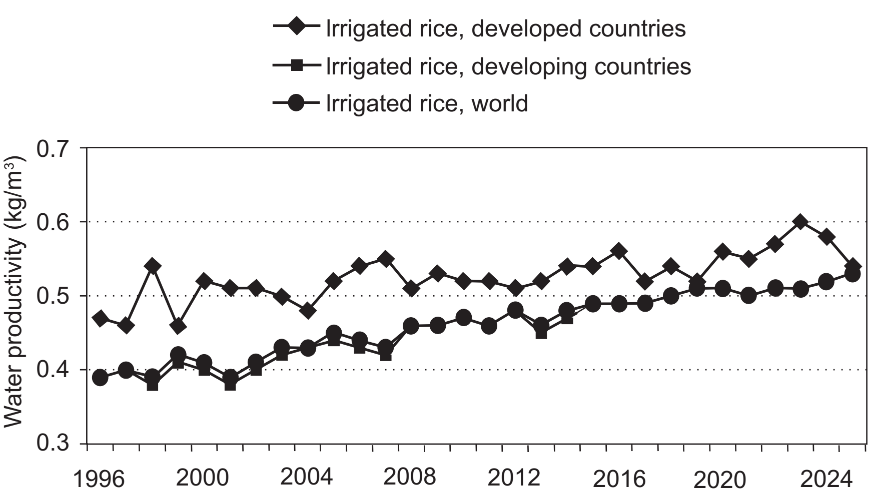
Source: IMPACT-WATER assessments, 2002.

Changes In Water Productivity between 1995 and 2025

To show the year-to-year variability of water productivity between 1995 and 2025, we report BAU results with one hydrologic regime, which regenerates the monthly hydrologic records for 1961–90. Our projections of water productivity show variation from 1995 to 2025 for both irrigated rice and other cereals, both in developed and developing countries and worldwide (Figures 4.8 and 4.9). This year-to-year variation is caused by climate variability, which affects water availability, and thus water productivity. Based on assumptions of area and yield growth and water supply enhancement, water productivities are projected to increase significantly between 1995 and 2025. For example, water productivity of other cereals will increase from 1.0 to 1.4 kilograms per cubic meter in developed countries, 0.6 to 1.0 kilograms per cubic meter in developing countries, 0.7 to 1.1 kilograms per cubic meter globally.

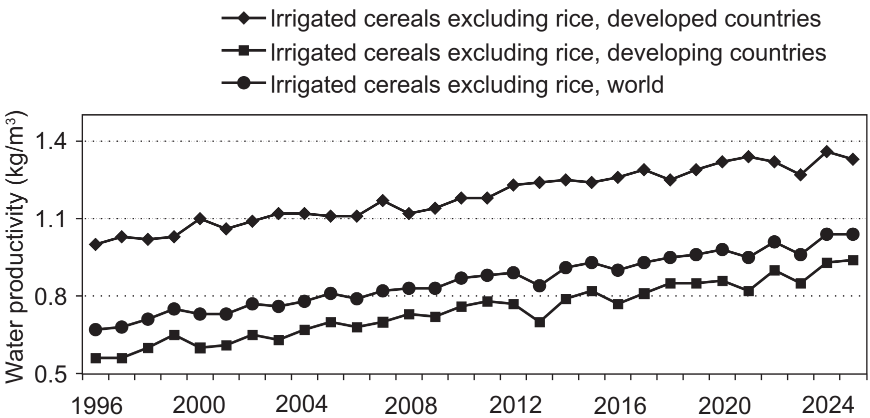
Figures 4.10 and 4.11 compare crop yield and water consumption between 1995 and 2025 for rice and other cereals, respectively, to give insight into the major cause of water productivity increases over the period. As can be seen, crop yield increases and water consumption per hectare decreases. Water consumption per hectare depends on the change in total consumption and the change in crop area.

Figure 4.8—Water productivity of irrigated rice, 1995–2025



Source: IMPACT-WATER assessments and projections, 2002.

Figure 4.9—Water productivity of irrigated cereals excluding rice, 1995–2025



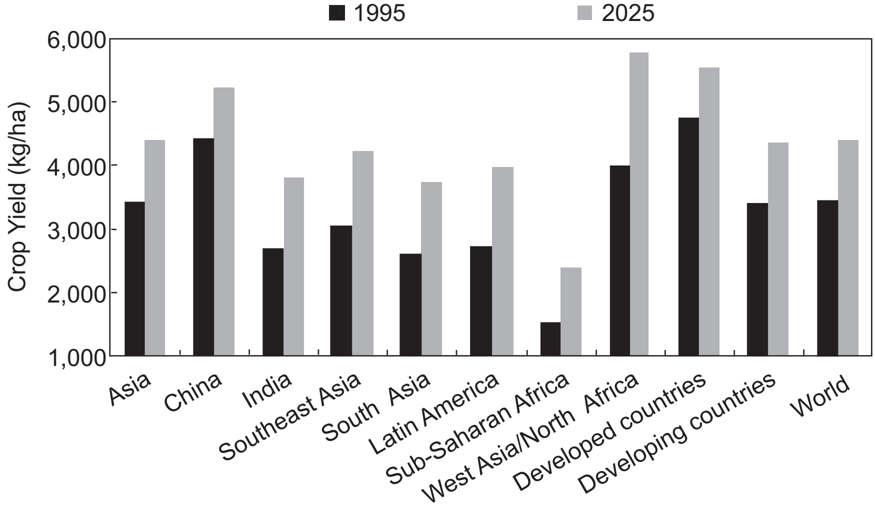
Source: IMPACT-WATER assessments and projections, 2002.

The model projects a relatively small increase in irrigated cereal crop area at 24 million hectares (10 percent) worldwide from 1995 to 2025. Total realized crop water consumption is further determined by the change in water withdrawal capacity, basin efficiency, rainfall harvest, crop consumption requirements, and the amount of water taken by non-irrigation sectors. Under BAU, total global water withdrawals are projected to increase by 23 percent from 1995 to 2025, with the increase mainly used for non-irrigation sectors (increasing by 62 percent worldwide from 1995 to 2025), leading to an increase in total consumption. Water consumption can be reduced, however, because the projected increase of effective river basin water use efficiency will decrease crop demand. All of these factors result in a 3.9 percent increase in consumptive water use for irrigation worldwide. Overall, as can be seen in Figures 4.10 and 4.11, the change of water consumption per hectare is small compared with the change of crop yield. The increase of water productivity results mainly from increases in crop yield.

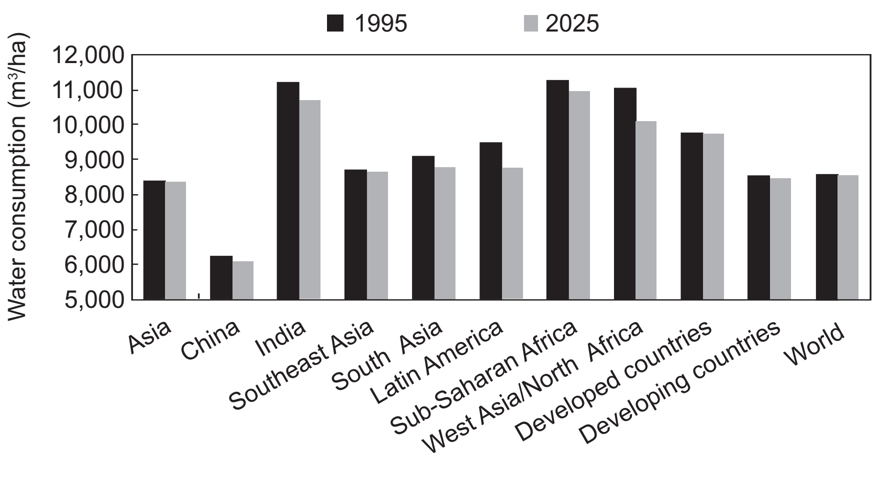
Water productivity for irrigated crops is higher than that of rainfed crops in developing countries (Figures 4.12 and 4.13). The difference becomes larger over time because of the higher increase in irrigated yield and the increase in water use efficiency over time. However, the water productivity of irrigated crops is not higher than that of rainfed crops everywhere in the world. As observed in Figures 4.14

Figure 4.10—Crop yield and water consumption of rice per hectare, 1995 and 2025

(a) Crop yield



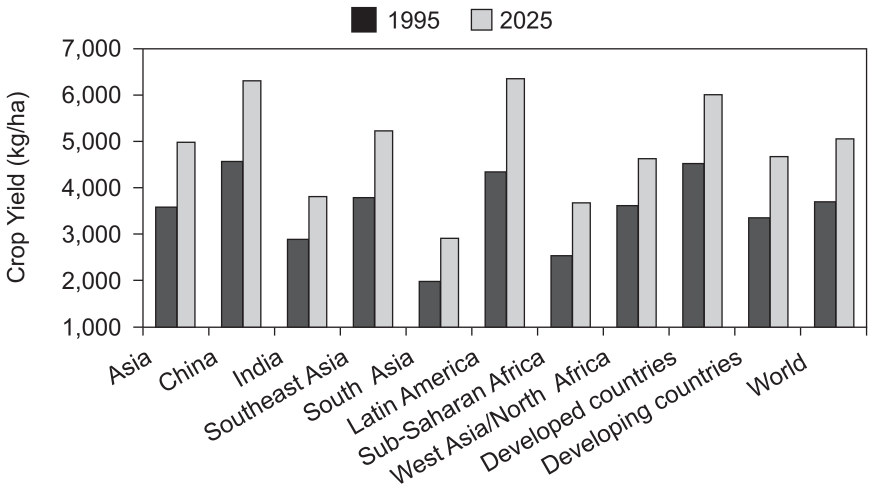
(b) Water consumption per hectare



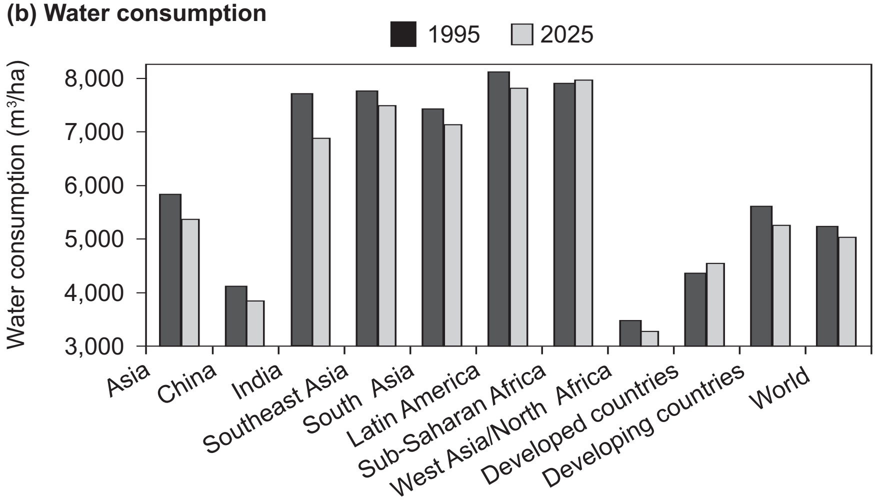
Source: IMPACT-WATER assessments and projections, 2002.

Figure 4.11—Crop yield and water consumption of cereals excluding rice per hectare, 1995 and 2025

(a) Crop yield

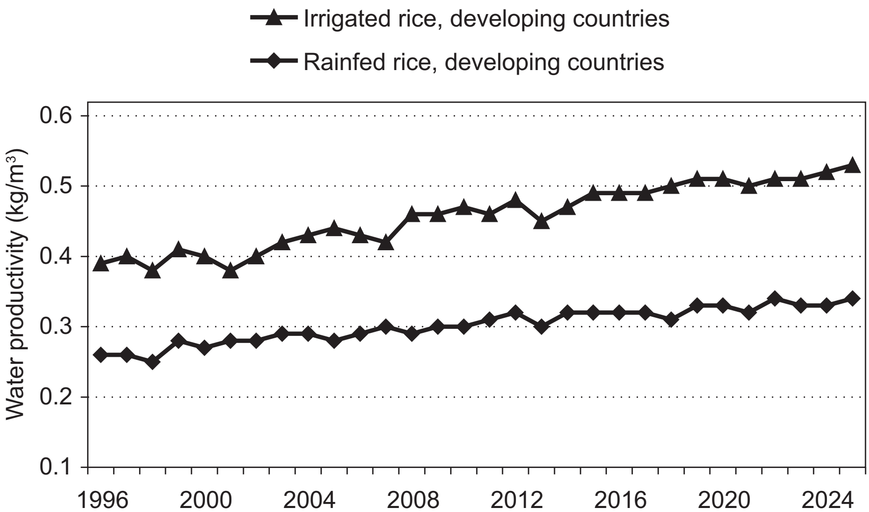


(b) Water consumption



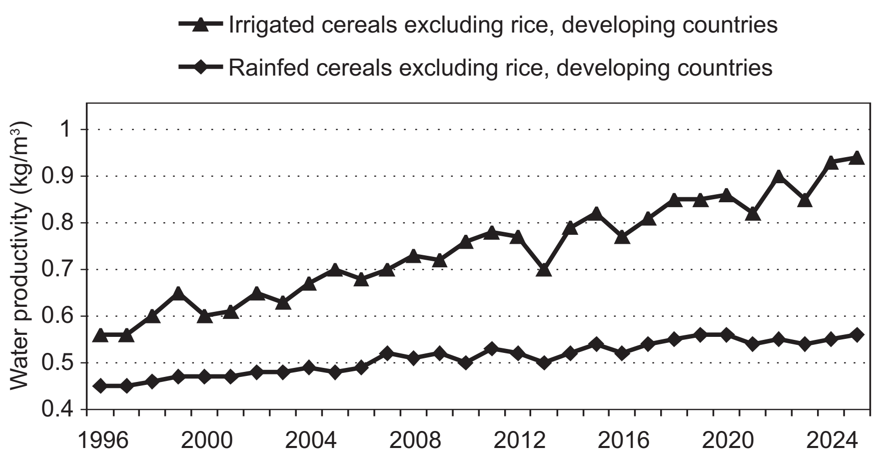
Source: IMPACT-WATER assessments and projections, 2002.

Figure 4.12—Water productivity for irrigated and rainfed rice in developing countries, 1995–2025



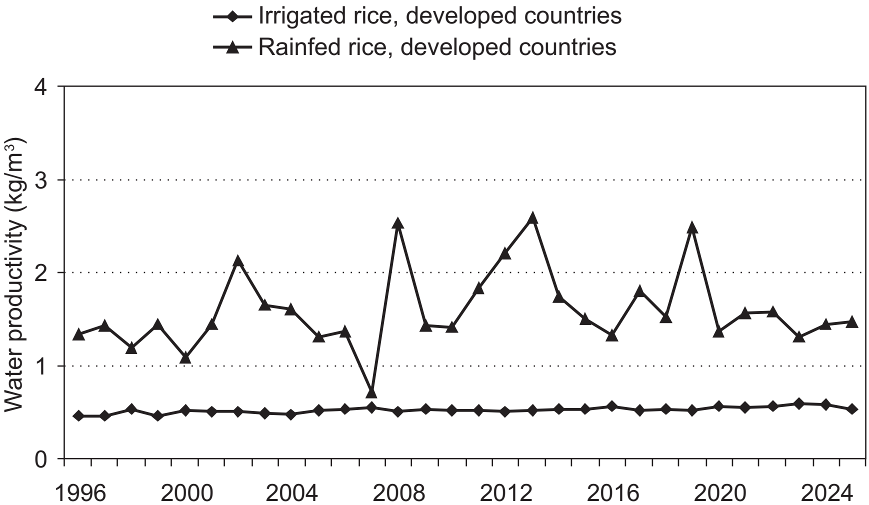
Source: IMPACT-WATER assessments and projections, 2002.

Figure 4.13—Water productivity for irrigated and rainfed cereals excluding rice in developing countries, 1995–2025



Source: IMPACT-WATER assessments and projections, 2002.

Figure 4.14—Water productivity for irrigated and rainfed rice in developed countries, 1995–2025



Source: IMPACT-WATER assessments and projections, 2002.

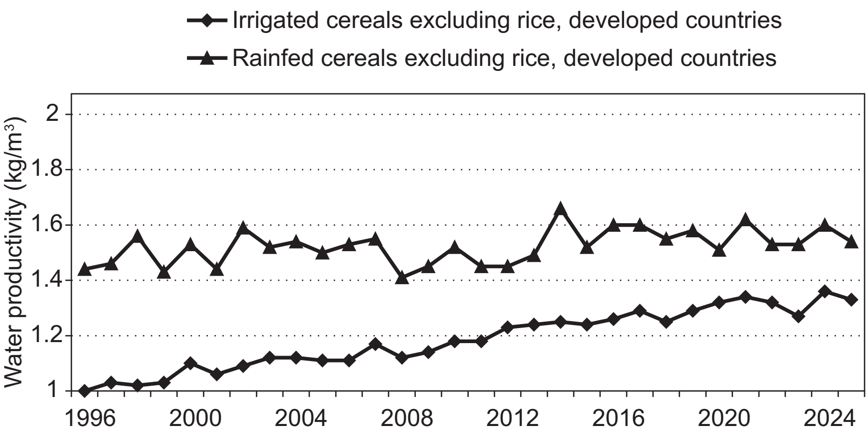
and 4.15, the curve of irrigated crops is below the curve of rainfed crops in developed countries for both rice and other cereals over the same period. This indicates the existence of relatively favorable rainfall conditions for crop growth and high rainfed crop yields associated with infrastructure and other inputs to rainfed crops in developed countries, compared with those in developing countries.

THE FUTURE FOR FOOD

Food Demand

With slowing population growth rates and increasing diversification of diets away from cereals given rising prosperity and changing dietary preferences, annual growth in cereal demand is projected to decline worldwide to 1.3 percent between 1995 and 2025 from 2.2 percent in 1965–95 (and 1.7 percent, 1970–2000). Nevertheless, the projected absolute increase in cereal demand of 828 million metric tons (Table 4.7) is nearly as large as the 846 million metric ton increase of the

Figure 4.15—Water productivity for irrigated and rainfed cereals excluding rice in developed countries, 1995–2025



Source: IMPACT-WATER assessments and projections, 2002.

preceding 30 years. Growth in food demand is concentrated in developing countries, which also undergo a change in the composition of cereal demand from rising incomes and rapid urbanization. Per capita food consumption of maize and coarse grains declines as consumers shift to wheat and rice, livestock products, and fruits and vegetables. In much of Asia, an additional shift occurs from rice to wheat. The projected strong growth in meat consumption, in turn, substantially increases cereal consumption for animal feed, particularly maize. The developing country presence in global food markets increases substantially. Under BAU, 86 percent of the projected increase in global cereal consumption between 1995 and 2025 comes from developing countries. Because of their larger, more urbanized populations and rapid economic growth, developing countries in Asia account for just over half the increase in global demand for cereals, with China alone accounting for one-quarter (Table 4.7).

Global demand for meat will grow much faster than that for cereals. Worldwide, demand for meat is forecast to increase by 70 percent between 1995 and 2025, with 86 percent of the increase occurring in developing countries, where meat demand more than doubles over 30 years (Table 4.8). China alone accounts for 39 percent of this increase, compared with India's 4 percent.

Poultry accounts for 41 percent of the global increase in demand for meat under BAU, reaching 33 percent of total meat demand in 2025, significantly higher than the 28 percent of total meat it accounted for in 1995, reflecting a dramatic shift in

Table 4.7—Cereal demand and total cereal production under the business-as-usual scenario, 1995 and 2025

	Cereal demand (million mt)						Cereal production (million mt)	
	1995 baseline estimates			2025 BAU projections			1995 baseline estimates	2025 BAU projections
Region/Country	Food	Feed	Total	Food	Feed	Total		
Asia	554.7	157.7	794.3	751.1	348.5	1,228.2	726.5	1,092.8
China	230.9	105.8	375.0	264.6	253.8	581.4	357.6	541.6
India	152.0	6.7	171.3	231.4	22.7	274.7	174.8	256.8
Southeast Asia	84.3	15.0	113.5	123.7	31.1	176.0	106.4	170.2
South Asia excluding India	49.2	1.7	54.9	89.4	4.1	101.6	51.1	80.9
Latin America (LA)	58.4	58.2	137.4	86.5	116.7	238.7	117.0	222.4
Sub-Saharan Africa (SSA)	61.5	3.8	78.4	134.6	9.2	172.4	67.8	137.7
West Asia/North Africa (WANA)	72.9	30.9	120.2	117.5	58.0	202.0	82.4	119.5
Developed countries	154.0	412.2	686.4	164.4	497.1	802.5	794.0	1,050.0
Developing countries	731.7	233.4	1,092.2	1,074.7	514.9	1,803.9	983.8	1,564.2
World	**885.7**	**645.7**	**1,778.6**	**1,239.0**	**1,011.9**	**2,606.4**	**1,777.7**	**2,614.2**

Sources: 1995 baseline data are author estimates based on FAO (1998b). 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates business-as-usual scenario; million mt, million metric tons.

taste from red meat to chicken. Increasingly, cereal crops are grown for animal feed to fuel the explosive rise in demand for meat rather than for direct human consumption. As a result, maize rises in importance relative to wheat and rice, accounting for 45 percent of the incremental cereal demand during 1995–2025 and reaching 35 percent of total cereal demand in 2025 compared with 31 percent in 1995. Soybeans and meals also show fast demand growth, increasing by 77 percent and 70 percent, respectively, between 1995 and 2025 (Table 4.8).

Demand growth for noncereal staple food commodities is also strong in developing countries under BAU. In many parts of SSA, roots and tubers—especially cassava, sweet potatoes, and yams—are a major source of sustenance. In the late 1990s, they accounted for 20 percent of calorie consumption in the region, with an even higher concentration in the diets of the poor. In much of Asia and LA, roots and tubers provide an important, supplemental source of carbohydrates, vitamins, and amino acids in food systems that are dominated by other commodities. These patterns are projected to continue, with total root and tuber demand in the developing world increasing by 65 percent (282 million tons) between 1995 and 2025. SSA is projected to account for 47 percent of this increase, indicating that roots and tubers will continue to be of crucial importance to the diet in that region (Table 4.8). Asia also accounts for a significant amount of the total increase, with east Asia accounting for 21 percent, and South Asia 14 percent.

Production, Area, and Yield

Production growth in meat, soybeans, meals, and roots and tubers generally follows the trends in demand growth (Table 4.9). However, for meats, meals, and roots and tubers, production growth in developing countries as a group is somewhat slower than demand growth, which leads to increasing imports as shown below. Soybean production growth lags demand in Asia, but outpaces demand growth in LA.

Cereal production in developing countries as a group will not keep pace with increases in demand. Cereal harvested area is expected to grow only slowly in the coming decades, by 0.40 percent per year in developing countries and 0.29 percent per year in the world as a whole (Table 4.10). Both irrigated and rainfed cereal areas harvested grow slowly, as will be discussed in more detail below. A large share of the most suitable land is already under cultivation, and factors limiting further land expansion include the slow projected growth of irrigation investment (see below), soil degradation, and rapid urbanization leading to conversion of cropland for other uses. The primary constraint to further crop area expansion is not purely a physical limit, however, but rather the projected flat or slowly declining real cereal prices that render expansion of cropland unprofitable in many cases (see discussion of cereal prices below). In Asia, cereal area is projected to increase by only 8 million

Table 4.8—Demand for meat, soybeans, meals, and roots and tubers under the business-as-usual scenario, 1995 and 2025

	1995 baseline estimates (million mt)				2025 BAU projections (million mt)			
Region/Country	**Meat**	**Soybeans**	**Meals**	**Roots and tubers**	**Meat**	**Soybeans**	**Meals**	**Roots and tubers**
Asia	72.1	32.4	45.2	245.1	153.8	68.6	101.4	354.9
China	47.4	16.9	16.2	170.8	101.9	38.8	38.7	218.9
India	4.1	4.7	10.3	25.0	10.1	11.5	27.6	60.0
Southeast Asia	8.0	3.7	6.2	31.0	19.4	7.5	15.5	48.0
South Asia excluding India	2.7	0.0	1.8	5.1	6.9	0.1	4.6	12.0
Latin America (LA)	23.0	36.4	13.1	49.6	46.4	69.7	27.1	76.3
Sub-Saharan Africa (SSA)	5.1	0.5	2.2	130.9	12.2	1.1	5.7	262.4
West Asia/North Africa (WANA)	6.9	0.6	5.0	14.3	14.6	1.4	10.0	27.3
Developed countries	96.4	66.4	83.2	198.0	115.5	97.9	104.9	203.8
Developing countries	101.6	64.9	59.5	435.2	220.5	133.9	138.1	717.1
World	**198.0**	**131.3**	**142.7**	**633.3**	**336.0**	**231.8**	**243.0**	**920.9**

Sources: 1995 baseline data are author estimates based on FAO (1998b); 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates busines-as-usual scenario; million mt, million metric tons.

Table 4.9—Production of meat, soybeans, meals, and roots and tubers under the business-as-usual scenario, 1995 and 2025

	1995 baseline estimates (million mt)				2025 BAU projections (million mt)			
Region/Country	Meat	Soybeans	Meals	Roots and tubers	Meat	Soybeans	Meals	Roots and tubers
Asia	69.3	21.9	45.5	255.7	147.9	44.6	80.0	340.9
China	47.5	14.3	16.7	168.9	101.9	27.1	30.3	211.4
India	4.3	4.7	14.4	25.2	10.6	11.6	26.8	48.3
Southeast Asia	8.0	2.2	5.2	45.8	19.2	4.6	8.6	54.6
South Asia excluding India	2.7	0.0	1.8	5.0	6.6	0.0	3.4	11.5
Latin America (LA)	23.6	40.3	31.1	49.5	48.0	95.6	53.6	82.3
Sub-Saharan Africa (SSA)	4.9	0.5	2.6	130.9	12.0	1.0	4.4	248.0
West Asia/North Africa (WANA)	5.9	0.3	2.3	14.7	11.9	0.5	4.0	29.6
Developed countries	97.4	68.4	65.9	186.1	119.4	90.3	107.9	223.6
Developing countries	100.6	62.9	76.8	447.2	216.5	141.5	135.1	697.2
World	**198.0**	**131.3**	**142.7**	**633.3**	**336.0**	**231.8**	**243.0**	**920.9**

Source: 1995 baseline data are author estimates based on FAO (1998b). 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates busines-as-usual scenario; million mt, million metric tons.

hectares, with an actual decline in rainfed cereal area (Table 4.10). SSA and LA have more potential for area expansion, with area under cereal production projected to expand by 30 million hectares in SSA (of which 28 million is rainfed area) and by 16 million hectares in LA during 1995–2025 (Table 4.10).

With slow growth in area, increases in cereal production are thus highly dependent on increases in productivity. But increases in crop yields are slowing across all cereals and all regions, with the notable exception of SSA, where yields are projected to recover from past stagnation. Yield growth rates in most of the world have been slowing since the early 1980s. In the developed world, the slowdown was primarily policy-induced, as North American and European governments reduced cereal stocks and scaled back farm-price support programs in favor of direct payments to farmers, while in Eastern Europe and the former Soviet Union economic collapse and subsequent economic reforms further depressed productivity. Factors contributing to the slowdown in cereal productivity growth in developing countries, particularly in Asia, include high levels of input use (meaning that it takes increasing input requirements to sustain yield gains), slowing public investment in crop research and irrigation infrastructure, and growing water shortages as irrigation development slows and nonagricultural water demand diverts water from agriculture. This slowdown is projected to continue, with the global yield growth rate for

Table 4.10—Irrigated and rainfed cereal area under the business-as-usual scenario, 1995 and 2025

Region/Country	Irrigated area (million ha)		Rainfed area (million ha)		Total cereal area (million ha)	
	1995 baseline estimates	2025 BAU projections	1995 baseline estimates	2025 BAU projections	1995 baseline estimates	2025 BAU projections
Asia	152.9	168.5	136.9	129.4	289.7	297.9
China	62.4	67.1	26.2	29.0	88.6	96.1
India	37.8	47.1	62.3	48.9	100.1	96.0
Southeast Asia	19.2	20.3	29.8	32.2	48.9	52.5
South Asia excluding India	19.9	21.0	5.6	5.5	25.5	26.5
Latin America (LA)	7.5	9.8	41.8	55.6	49.3	65.4
Sub-Saharan Africa (SSA)	3.3	4.9	69.8	97.7	73.0	102.6
West Asia/North Africa (WANA)	9.8	10.8	34.0	36.0	43.7	46.8
Developed countries	41.8	44.9	192.1	195.7	233.9	240.6
Developing countries	171.3	192.6	282.2	318.5	453.5	511.1
World	**213.1**	**237.5**	**474.3**	**514.12**	**687.4**	**751.7**

Sources: 1995 baseline data are based on FAO (1999) for cereals in developing countries and Cai and Rosegrant (1999) for crops in basins in the United States, China, and India, and noncereal crops in all countries and regions. 2025 data are IMPACT-WATER projections, 2002.

Notes: BAU indicates busines-as-usual scenario; million ha, million hectares.

Table 4.11—Irrigated and rainfed cereal yield under the business-as-usual scenario, 1995 and 2025

Region/Country	Irrigated yield (mt/ha) 1995 baseline estimates	Irrigated yield (mt/ha) 2025 BAU projections	Rainfed yield (mt/ha) 1995 baseline estimates	Rainfed yield (mt/ha) 2025 BAU projections	Total cereal yield (mt/ha) 1995 baseline estimates	Total cereal yield (mt/ha) 2025 BAU projections
Asia	3.23	4.57	1.70	2.50	2.51	3.67
China	4.23	6.02	3.59	4.74	4.04	5.64
India	2.65	3.74	1.20	1.65	1.75	2.67
Southeast Asia	3.05	4.39	1.61	2.53	2.17	3.25
South Asia excluding India	2.19	3.34	1.24	1.94	1.98	3.05
Latin America (LA)	4.07	5.66	2.07	3.00	2.37	3.40
Sub-Saharan Africa (SSA)	2.16	3.23	0.85	1.25	0.91	1.34
West Asia/North Africa (WANA)	3.58	4.91	1.40	1.85	1.88	2.56
Developed countries	4.44	6.13	3.17	3.96	3.39	4.36
Developing countries	3.25	4.60	1.51	2.13	2.17	3.06
World	**3.48**	**4.89**	**2.18**	**2.83**	**2.58**	**3.48**

Sources: 1995 baseline data are based on FAO (1999) for cereals in developing countries and Cai and Rosegrant (1999) for crops in basins in the United States, China, and India, and noncereal crops in all countries and regions. 2025 data are IMPACT-WATER projections, 2002.
Notes: BAU indicates busines-as-usual scenario; mt/ha, metric tons per hectare.

all cereals declining from 1.5 percent per year during 1982–95 to 1.0 percent per year during 1995–2025; and average crop yield growth in developing countries, declining from 1.9 percent per year to 1.2 percent.

Growing water shortages are a particularly important source of yield growth decline, and a declining fraction of this irrigation water demand is met over time because irrigation water supply is increasingly being constrained, as indicated in the IWSR discussion above. Increasing water scarcity for irrigation directly contributes to slowing cereal yield growth in developing countries, as can be seen in the projected relative crop yields for irrigated cereal. Relative crop yield is the ratio of projected crop yield to the maximum economically attainable yield at given crop and input prices under zero water stress conditions. The fall in the relative crop yield index significantly hinders future yield growth. For developing countries as a group in 2025, the drop from 0.86 to 0.75 represents an annual 0.68 million tons per hectare in crop yield foregone through increased water stress or an annual loss of cereal production of 130 million metric tons—equivalent to China's annual rice crop and double the U.S. wheat crop in the late 1990s (Table 4.12).

Table 4.12—Relative irrigated cereal crop yields under the business-as-usual scenario, 1995 and 2025

	Relative irrigated cereal crop yields	
Region/Country	1995 baseline estimates	2025 BAU projections
Asia	0.87	0.76
China	0.89	0.78
India	0.84	0.72
Southeast Asia	0.97	0.87
South Asia excluding India	0.87	0.73
Latin America (LA)	0.94	0.76
Sub-Saharan Africa (SSA)	0.96	0.77
West Asia/North Africa (WANA)	0.68	0.57
Developed countries	0.89	0.87
Developing countries	0.86	0.75
World	**0.87**	**0.77**

Sources: Authors' estimates and IMPACT-WATER projections, 2002.
Note: BAU indicates busines-as-usual scenario.

International Trade and Prices

By 2020 under BAU, with developing countries unable to meet cereal demand from their own production, international trade becomes even more vital in providing food to many regions of the globe. Net cereal import demand from the developing world is projected to increase from 107 million metric tons in 1995 to 245 million metric tons in 2025, with Asian nations—particularly China—boosting their imports enormously. Developing countries as a group also increase their imports of meat and roots and tubers, and shift from net exporters of meals to net importers. Asia significantly increases the import of soybeans, while LA dramatically increases soybean exports (Table 4.13).

The substitution of cereal and other food imports for irrigated agricultural production (so-called imports of "virtual water") can be an effective means for reducing agricultural water use (Allan 1996). The virtual water concept is based on the principle of comparative advantage in international trade. Maize is exported from the United States in significant part because it can be grown without irrigation given the exceptionally favorable agroclimatic conditions of the "corn belt." Water-scarce countries, such as much of WANA, have a disadvantage in growing water-intensive crops such as cereals, and could improve water availability for other crops and other sectors by increasing their reliance on cereal imports. Countries with relatively plentiful water, such as Viet Nam, Thailand, and Myanmar, in turn have a comparative advantage in exporting water-intensive crops, like rice, to water-scarce countries (IWMI 2000).

Table 4.13—Net food trade under the business-as-usual scenario, 1995 and 2025

	1995 baseline estimates (million mt)					2025 BAU projections (million mt)				
Region/Country	**Cereals**	**Meat**	**Soybeans**	**Meals**	**Roots and tubers**	**Cereals**	**Meat**	**Soybeans**	**Meals**	**Roots and tubers**
Asia	-67.7	-2.8	-10.5	0.3	10.6	-139.7	-5.9	-24.0	-21.4	-14.0
China	-17.4	0.1	-2.6	0.5	-1.9	-42.0	0.0	-11.7	-8.4	-7.5
India	3.6	0.2	0.0	4.1	0.2	-19.1	0.5	0.1	-0.8	-11.7
Southeast Asia	-7.0	0.0	-1.5	-1.0	14.8	-6.2	-0.2	-2.9	-6.9	6.6
South Asia excluding India	-3.8	0.0	0.0	0.0	-0.1	-21.0	-0.3	-0.1	-1.2	-0.5
Latin America (LA)	-20.4	0.6	3.9	18.0	-0.1	-16.8	1.6	25.9	26.5	6.0
Sub-Saharan Africa (SSA)	-9.8	-0.2	0.0	0.4	0.0	-34.9	-0.2	-0.1	-1.3	-14.4
West Asia/North Africa (WANA)	-37.8	-1.0	-0.3	-2.7	0.4	-83.0	-2.7	-0.9	-6.0	2.3
Developed countries	107.5	1.0	2.0	-17.3	-11.9	245.2	4.0	-7.6	3.0	20.6
Developing countries	-107.5	-1.0	-2.0	17.3	11.9	-245.2	-4.0	7.6	-3.0	-20.6
World	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Sources: 1995 baseline data are author estimates based on FAO (1998b). 2025 data are IMPACT-WATER projections, 2002.

Note: Negative values indicate net imports; positive values, net exports. BAU indicates business-as-usual scenario; million mt, million metric tons.

BAU shows the vital importance of trade in relation to virtual water. The increase in developing country cereal imports by 138 million metric tons between 1995 and 2025 is equivalent to saving 147 cubic kilometers of water at 2025 water productivity levels, or 8 percent of total water consumption and 12 percent of irrigation water consumption in developing countries in 2025. The water (and land) savings from projected large increases in food imports by developing countries are particularly beneficial if they are the result of strong economic growth that generates the necessary foreign exchange to pay for the food imports. However, even when rapidly growing food imports are primarily a result of rapid income growth, they often act as a warning signal to national policymakers concerned with heavy reliance on world markets, and can induce pressure for trade restrictions that can threaten growth and food security in the longer term. More serious food security problems arise when high food imports are the result of slow agricultural and economic development that fails to keep pace with basic food demand growth driven by population growth. Under these conditions, it may be impossible to finance the required imports on a continuing basis, further deteriorating the ability to bridge the gap between food consumption and food required for basic livelihood. As such, "hot spots" for food trade gaps occur in SSA, where cereal imports are projected to more than triple by 2025 to 35 million metric tons, and in WANA, where cereal imports are projected to increase from 38 million metric tons in 1995 to 83 million metric tons in 2025. The reliance on water-saving cereal imports in WANA makes economic and environmental sense, but must be supported by enhanced nonagricultural growth. It is highly unlikely that SSA could finance the projected level of imports internally; instead international financial or food aid would be required. Failure to finance these imports would further increase food insecurity and pressure on water resources in this region.

Sharp decreases in food prices over the last three decades were a great benefit to the poor, who spend a large share of income on food. Real world prices of wheat, rice, and maize fell by 47, 59, and 61 percent, respectively, between 1970 and 2000. But international cereal prices are projected to decline much more slowly during the next two decades, a significant break from past trends, with a projected increase in the price of maize (Table 4.14). Prices of meat and other commodities also decline far less than in previous decades. This tighter predicted future price scenario indicates additional shocks to the agricultural sector—particularly shortfalls in meeting agricultural water and other input demands—that could seriously pressure food prices upward.

Irrigated and Rainfed Production, 1995

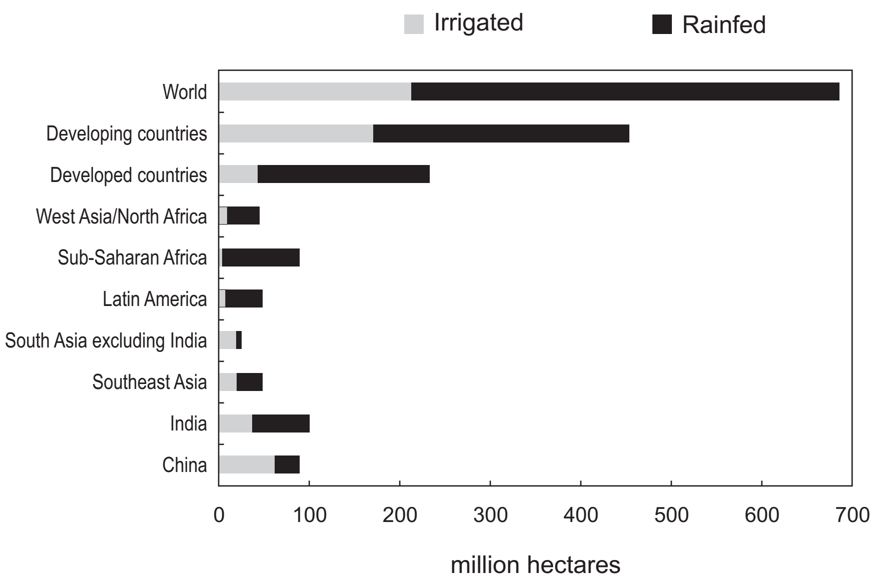
Rainfed and irrigated cereal area and yield for the 1995 baseline were estimated based on data from FAO (1999) and Cai and Rosegrant (1999).[4] Figures 4.16 to 4.18

Table 4.14—World food prices under the business-as-usual scenario, 1995 and 2025

	World food prices (US$/mt)	
Commodity	**1995 baseline estimates**	**2025 BAU projections**
Rice	285	221
Wheat	133	119
Maize	103	104
Other coarse grains	97	82
Beef	1,808	1,660
Pork	2,304	2,070
Sheep	2,918	2,621
Poultry	735	700
Potatoes	209	180
Sweet potatoes	134	90
Other roots and tubers	106	81
Soybeans	247	257
Meals	199	262

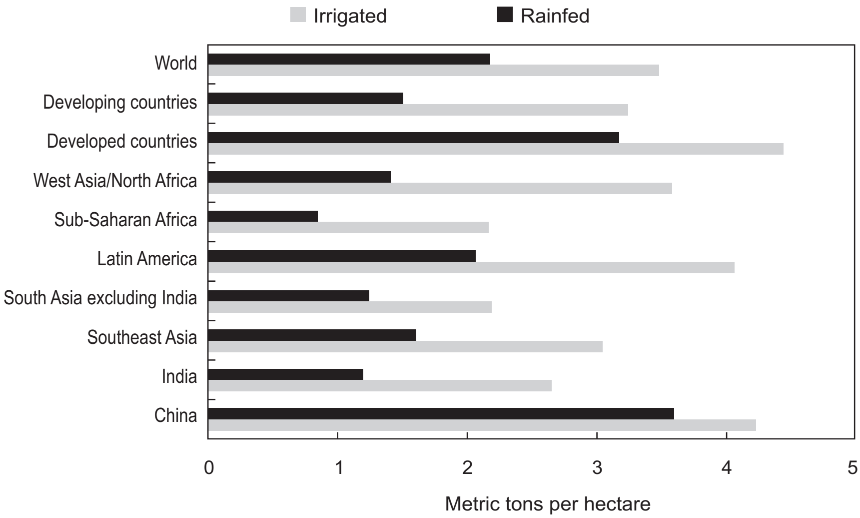
Sources: 1995 baseline data are based on FAO (1998c), IMF (1997), USDA-NASS (1998), and World Bank (1997). 2025 data are IMPACT-WATER projections, 2002.
Note: BAU indicates business-as-usual scenario; US$/mt, U.S. dollars per metric ton.

Figure 4.16—Cereal area, 1995



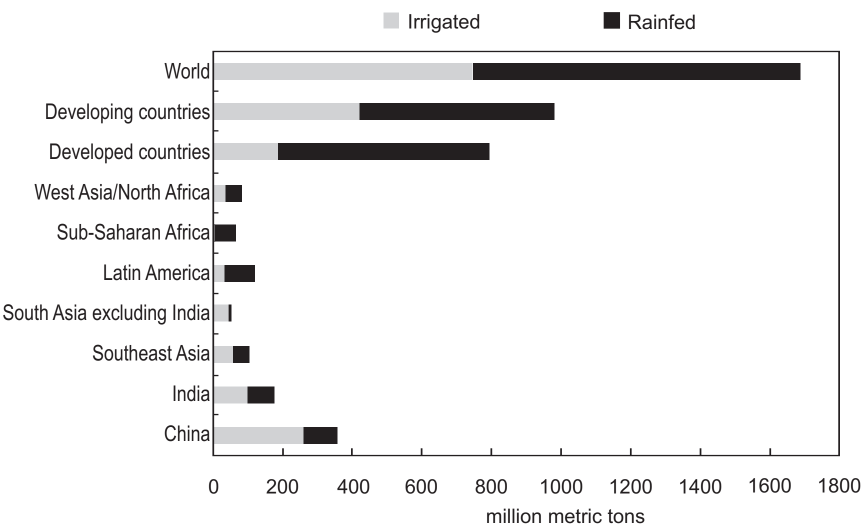
Source: Author estimates based on FAO (1999) and Cai and Rosegrant (1999).

Figure 4.17—Cereal yield, 1995



Source: Author estimates based on FAO (1999) and Cai and Rosegrant (1999).

Figure 4.18—Cereal production, 1995



Source: Author estimates based on FAO (1999) and Cai and Rosegrant (1999).

show rainfed and irrigated cereal area, yield, and production in selected countries and aggregated regions in 1995. Developing countries rely substantially more on irrigated agriculture than developed countries, with 38 percent of all cereal area irrigated, accounting for 59 percent of total cereal production. Conversely, only 18 percent of all cereal area is irrigated in the developed world, accounting for 23 percent of total cereal production. Rainfed cereal yield in the developed world is almost double the rainfed yield in the developing world, and is only slightly lower than the irrigated yield in the developing world. As a result, rainfed cereal production in the developed world contributes 59 percent of global rainfed production, and 34 percent of total cereal production.

For some countries and regions with an arid or semi-arid climate, the fraction of rainfed crops is very low, for example, zero percent of the cereal area harvested in Egypt and 7.4 percent in Pakistan is rainfed.[5] Because rice is the dominant crop in Japan and South Korea, rainfed cereal harvested area occupies only 10 and 16 percent, respectively, of the total area harvested. Other countries in which the fraction of rainfed harvested cereal area is below 50 percent include Bangladesh, China, Malaysia, Indonesia, and Viet Nam. The fraction of rainfed cereal harvested area in Nigeria, all SSA countries, and some South American countries such as Argentina and Brazil is over 90 percent, while in LA as a whole the percentage is a slightly lower 85 percent.

Globally, 69 percent of cereal area planted is rainfed including 40 percent of rice, 66 percent of wheat, 82 percent of maize, 86 percent of other grains, and 85 percent of soybeans. The global rainfed harvested area of rice, wheat, maize, other cereals, soybeans, potatoes, sweet potatoes, and cassava and other roots is 560 million hectares in 1995, with cereals representing 85 percent of this total. Worldwide rainfed cereal yield is about 2.2 metric tons per hectare, which is about 65 percent of the irrigated yield. Rainfed cereal production accounts for 58 percent of worldwide cereal production.

Globally, the harvested area of rice is 146 million hectares, of which approximately 87 million hectares are irrigated, and 59 million hectares are rainfed. Developed countries plant very little rainfed rice, while it occupies approximately 42 percent, or 59 million hectares of the total rice area, in developing countries. Developing countries are also responsible for almost all production worldwide, with 97 percent of the total world rice yield coming from those countries. Rainfed rice yield in developing countries is 1.4 tons per hectare or about 44 percent of the total irrigated rice yield in developing countries; this amounts to 24 percent of the developing country total, and 23 percent of world production.

In 1995, 222 million hectares of wheat was harvested globally, 66 percent of which was rainfed, the remaining 34 percent irrigated. About 83 percent of the area planted to wheat in developed countries was rainfed, while in developing countries slightly less than half the total wheat area planted was rainfed. Rainfed wheat yields in developed and developing countries are approximately 2.5 and 1.2 tons per hectare, respectively, while the irrigated yields are slightly higher at 2.9 and 1.7 tons per hectare, respectively. Rainfed wheat production contributes 33 percent of the total yield in developing countries, 81 percent in developed countries, and 52 percent worldwide.

Maize is grown under rainfed conditions more often than rice and wheat. Of the roughly 138 million hectares sown to maize in the world, 82 percent is rainfed, while 18 percent is irrigated. Over 60 percent of the total maize area worldwide is in developing countries, where the average rainfed maize yield is 3.4 tons per hectare; developing countries lag behind at 1.8 tons per hectare. Irrigated yields are higher at 4.2 tons per hectare in developed countries and 2.9 tons per hectare in developing countries. Rainfed maize production contributes 66 percent of the total yield in developing countries, 81 percent in developed countries, and 74 percent globally.

Global production of other coarse grains including barley, millet, oats, rye, and sorghum is predominantly rainfed, with 156 million rainfed hectares, accounting for 86 percent of the total world harvested area. In contrast to wheat and maize, other grains have a lower fraction of rainfed area in developed countries (80 percent) compared with developing countries (91 percent). The average rainfed yield of other grains in developed countries is 2.1 tons per hectare, while that of developing countries is much lower at 0.9 tons per hectare. Irrigated areas yield 3.5 tons of other grains per hectare in developed countries and 2.2 tons per hectare in developing countries. Rainfed production of other coarse grains contributes 80 percent of total yield in developing countries, 71 percent in developed countries, and 74 percent globally.

Approximately 62 million hectares of soybeans are harvested worldwide of which 53 million hectares are rainfed. Developed countries cultivate 91 percent of the total soybean area using rainfed agriculture, while 80 percent of the area in developing countries is rainfed. Unlike cereal crops, rainfed and irrigated soybean yields are similar. In developed countries, the irrigated soybean yield is 2.7 tons per hectare, slightly higher than the rainfed yield of 2.2 tons per hectare; in developing countries the irrigated yield is only slightly higher than the rainfed yield with both at approximately 1.8 tons per hectare.

Rainfed Agriculture versus Irrigated Agriculture—Changes to 2025

Total world irrigated area is projected to increase by 59 million hectares to 420 million hectares—just 16 percent—between 1995 and 2025. Cereals accounted for an

Table 4.15—Irrigated and rainfed cereal production under the business-as-usual scenario, 1995 and 2025

Region/Country	Irrigated production (million mt)		Rainted production (million mt)		Share of rainfed production (%)	
	1995 baseline estimates	2025 BAU projections	1995 baseline estimates	2025 BAU projections	1995 baseline estimates	2025 BAU projections
Asia	493	769	233	323	32	30
China	264	404	94	138	26	25
India	100	176	75	81	43	31
Southeast Asia	59	89	48	81	45	48
South Asia excluding India	44	70	7	11	14	13
Latin America (LA)	31	55	86	167	74	75
Sub-Saharan Africa (SSA)	7	16	59	122	89	89
West Asia/North Africa (WANA)	35	53	48	67	58	56
Developed countries	186	275	608	775	77	74
Developing countries	557	886	425	678	43	43
World	**742**	**1,161**	**1,033**	**1,453**	**58**	**56**

Sources: 1995 baseline data are based on FAO (1999) for cereals in developing countries and Cai and Rosegrant (1999) for crops in basins in the United States, China, and India. 2025 data are IMPACT-WATER projections, 2002.
Notes: BAU indicates business-as-usual scenario; million mt, million metric tons.

estimated 59 percent of world irrigated area in 1995; under BAU, in 2025 they account for 57 percent. Irrigated cereal area increases by 24.4 million hectares, an 11 percent increase over 1995 levels. Nearly all of this increase occurs in developing countries, with the largest increases in India and China. Developed country irrigation increases by only 5.4 million hectares, with a 3.1 million hectare increase in cereal irrigated area.

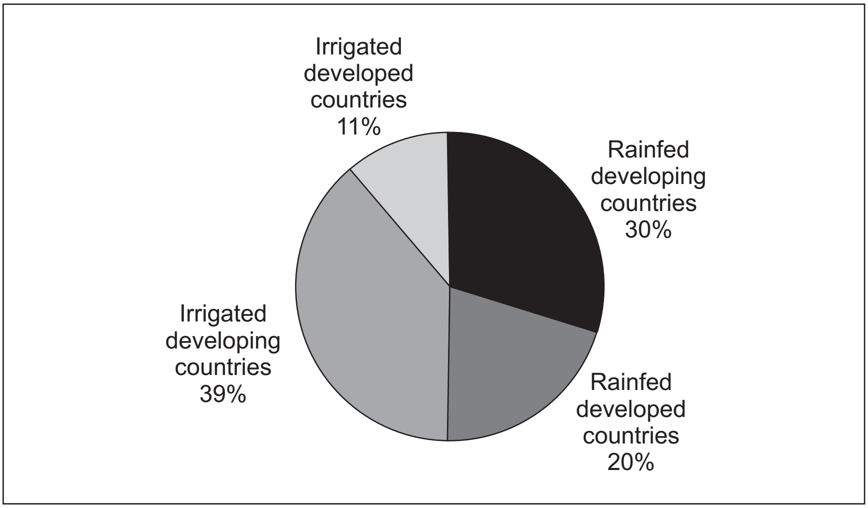
A more detailed breakdown of irrigated and rainfed cereal area, yield, and production is provided in Tables 4.10, 4.11, and 4.15. Worldwide, rainfed cereal area in 2025 is projected to be 514 million hectares, an 8 percent increase over 1995 levels (Table 4.10). Rainfed cereal area accounts for 68 percent of the total harvested area in 2025, down only slightly from 69 percent in 1995. In developing countries, the rainfed fraction of total area remains the same as 1995 levels at 62 percent. Developed countries, on the other hand, show a slight decrease from 82 percent of the total area planted using rainfed methods in 1995 to 81 percent in 2025.

The global average rainfed cereal yield under BAU is 2.8 metric tons per hectare in 2025, 30 percent higher than in 1995 (Table 4.11). Globally, irrigated cereal yield increases even more, with an overall increase of 40 percent (from 3.5 tons per hectare in 1995 to 4.9 tons per hectare in 2025). The developing world shows a rainfed yield increase of 0.6 metric tons per hectare (a 41 percent increase over 1995 levels), while irrigated yields increase 39 percent (from 3.3 to 4.6 metric tons per hectare). Rainfed yield in the developed world increases 0.8 metric tons per hectare over the period (an increase of 25 percent), while irrigated yields increase 1.7 metric tons or 38 percent.

Global rainfed production increases 41 percent over 1995 values, while irrigated production increases 56 percent (Table 4.10). Relative production increases are more pronounced in developing countries (particularly for rainfed production) at 60 and 59 percent for rainfed and irrigated production, respectively. Developed countries increase rainfed production by 27 percent, while irrigated production increases by 48 percent. Rainfed production accounts for 56 percent of total cereal production worldwide, down slightly from 58 percent in 1995. The developing world maintains its share of rainfed production (43 percent), and rainfed production in the developed world slightly decreases its share, from 77 percent in 1995 to 74 percent in 2025.

Figure 4.19 shows the sources of increased global cereal production during 1995–2025. Under BAU, irrigated and rainfed production each account for about half the total increase in cereal production between 1995 and 2025.

Figure 4.19—Share of irrigated and rainfed production in cereal production increase under the business-as-usual scenario, 1995–2025



Source: IMPACT-WATER assessments and projections, 2002.

Irrigation plays a dominant role in cereal production in developing countries, accounting for 57 percent of future cereal production growth in developing countries and four-fifths of the growth in global irrigated cereal production. The importance of rainfed cereal production at the global scale is in part a result of the dominance of rainfed agriculture in developed countries. More than 80 percent of cereal area in developed countries is rainfed, much of which is highly productive maize and wheat land such as that in the midwestern United States and parts of Europe. Rainfed cereal yields in developed countries averaged 3.2 metric tons per hectare in 1995, nearly as high as irrigated cereal yields in developing countries, and grow to 4 metric tons per hectare by 2025 under BAU. Rainfed agriculture remains important in developing countries as well. While rainfed yields in developing countries only increase from 1.5 metric tons per hectare to 2.1 metric tons per hectare by 2025, rainfed cereal production still accounts for 43 percent of the developing country total, the same percentage as in 1995.

SUMMARY

Water demand is projected to grow rapidly, particularly in developing countries. Irrigation remains the single largest water user over the 30-year projection period, but the increase in demand is much faster for domestic and industrial uses than for agriculture. Modeling results under BAU also show declining water supply reliability and relative crop yields, as well as worsening agricultural production vulnerability from water scarcity. Food production, demand, and trade and food prices are increasingly affected by declining water availability for irrigation. Given significantly faster growth in water demand in all sectors, developing countries are substantially more negatively affected by declining water availability for irrigation and other uses than developed countries. This is especially so for developing countries with arid climates, poor infrastructure development, and rapidly increasing populations. The increase in imports of "virtual water" through the import of water-intensive cereals is an important safety valve for many developing countries but does not fully compensate declining relative water supply for irrigation.

Rainfed agriculture contributes half the additional cereal production during 1995–2025, showing significant potential for maintaining food security and, importantly, implying the need to improve rainfed agriculture through rainfall harvesting and other means. Our projections indicate that water productivity of irrigated crops is also higher than that of rainfed crops in developing countries, but lower in developed countries. This shows that in developing countries irrigated agriculture is more efficient than rainfed agriculture in resource utilization and food production but also points to the untapped potential to increase the water productivity of rainfed crops through research and infrastructure investment. (The potential for increasing food production from rainfed agriculture is discussed further in Chapters 5 and 8).

Both the increase of crop yield and the reduction of water consumption through basin efficiency improvements contribute to increased water productivity, but the major contribution comes from increased crop yields. Therefore, investments in agricultural infrastructure and research are an essential complement to efforts to improve water use efficiency through investments in water management and infrastructure.

Worldwide and in large aggregated regions, water withdrawal is a small fraction of total renewable water, but for some countries and river basins (especially those arid and semi-arid regions) water withdrawal increasingly seems to threaten the minimum required environmental flow during 1995–2025. The conflict between irrigation and environmental uses and possible solutions for the resolution of this conflict is further addressed in Chapters 5 and 7.

Overall, to meet food demand and sustain minimum required environmental flow to 2025, investments, technology adoption, and policy reform in water and irrigation management are all necessary to maintain water supply reliability and to reduce water supply vulnerability for irrigation, especially in developing countries. More comprehensive analysis through alternative scenarios in terms of investment, technology, and policy variables follows in subsequent chapters.

NOTES

1. All results except when noted are based on the mean of 30 hydrologic samples specified based on the hydrologic regime between 1961 and 1990. The thirty hydrologic scenarios operate under the same assumptions but with various year sequences as given below:

Scenario 1:	*1961,*	*1962...*	*1990,*		
Scenario 2:	*1962,*	*1963...*	*1990,*	*1961,*	
Scenario 3:	*1963,*	*1964...*	*1990,*	*1961,*	*1962*
...					
Scenario 30:	*1961,*	*1962...*	*1988,*	*1989,*	*1990*

The projected results are reported as the mean across the 30 scenarios for each year during 1996–2025.

2. As noted in Chapter 3, estimates for connected households include households with access to both in-house piped water and to standpipes because comprehensive data was unavailable for households with in-house piped connections.

Thus the per capita water consumption differential between connected and unconnected households, while substantial, is lower than some estimates based on only in-house piped water connections.

3. Water productivity is generally defined as physical or economic output per unit of water application.
4. 1995 is the most recent year for which it was possible to assemble adequate data.
5. WANA as a whole is much more reliant on rainfed cereals, which account for 78 percent of harvested area.